GROUNDFISH RISK ASSESSMENT

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OVERVIEW

Our initial evaluation of groundfish vulnerability to non-fisheries risks indicates that groundfish appear to be at highest risk from systemic threats such as ocean acidification and change in average sea surface temperature. This evaluation represents a first step towards evaluating the vulnerability of groundfish to such risks.

EXECUTIVE SUMMARY

A recent development in the use of risk assessment is fisheries management is the productivity-susceptibility analyses (PSA) which have been used as an evaluation of the vulnerability of fish stocks to current fisheries management practices, based upon their susceptibility to the fishery and a suite of life history traits which indicate productivity (as a main factor in the resilience of the population). We used a modified PSA approach to provide information on the relative risk imposed by the various non-fisheries threats to the four species in the California Current. Habitat Suitability Probabilities (HSPs) describe the distribution of each species/life-history stage, and the overlap of the HSPs with the spatial distribution and intensity of the threat were used to determine the exposure to each threat (e.g. Figure GFii). Exposure combined with sensitivity to each threat provides a metric of susceptibility for the PSA.

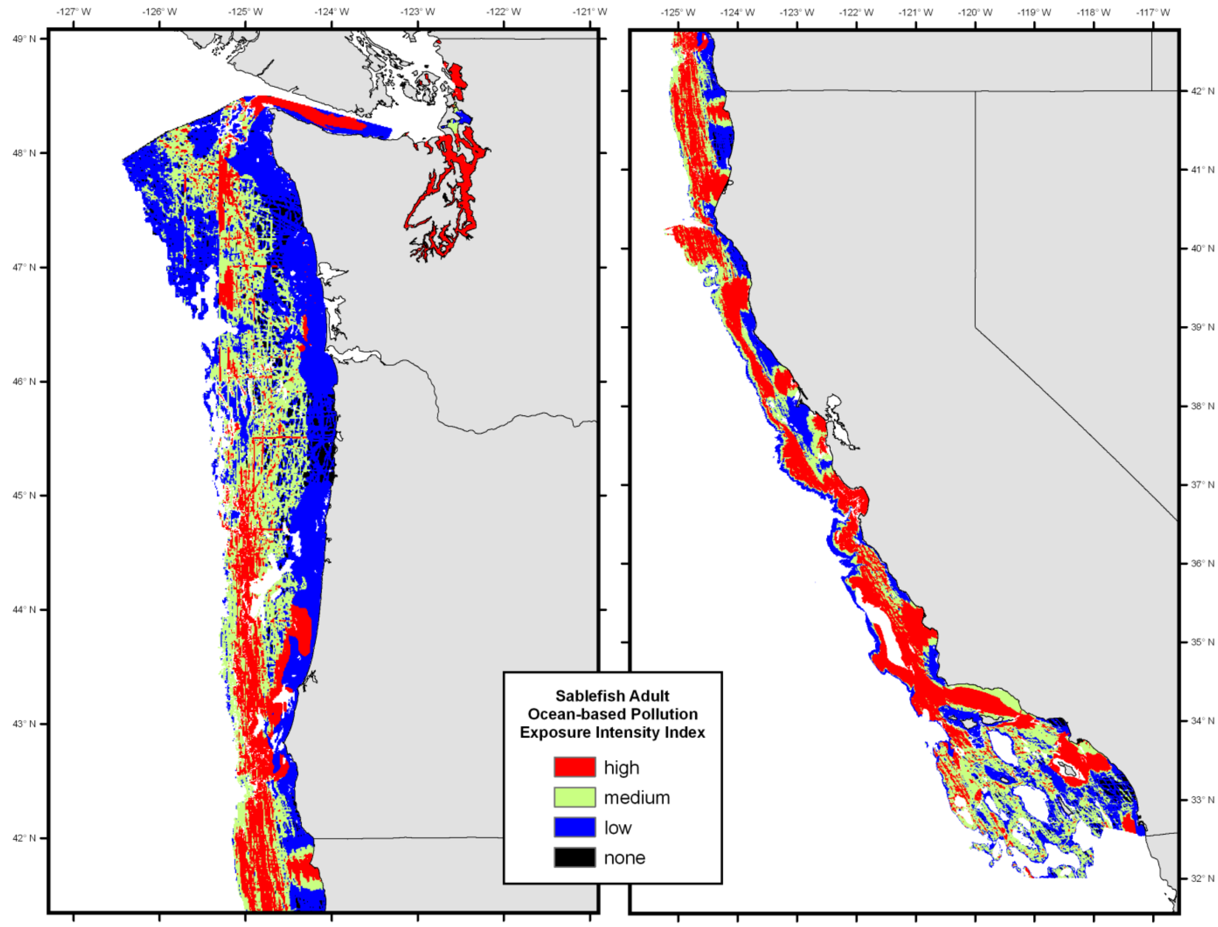

Figure GFRii. Exposure intensity index of ocean-based pollution for sablefish *Anoplopoma fimbria* adults. High = upper tercile, Medium = middle tercile, low = lower tercile.

DETAILED REPORT

INTRODUCTION

Quantitative risk assessment is a general analytical approach for describing the likelihood and magnitude of adverse consequences due to exposure to particular threats (and, if possible, cumulative impacts of multiple threats). In ecotoxicology, for example, risk is generally described using the response (or sensitivity) of a species to different levels of exposure to a threat (typically a chemical contaminant) (Suter, 2007). A recent development in the use of risk assessment is fisheries management is the productivity-susceptibility analyses (PSA) which have been used as an evaluation of the vulnerability of fish stocks to current fisheries management practices, based upon their susceptibility to the fishery and a suite of life history traits which indicate productivity (as a main factor in the resilience of the population) (Patrick et al., 2009, 2010; Hobday et al., 2011).This has been especially useful for data poor species and stock, where full assessments have not been conducted, and may not be currently feasible (Cope et al. 2011).

Both the ecotoxicological and PSA risk approaches allow an evaluation of the probability (and magnitude) of adverse effects given information about exposure to a stressor (e.g. a contaminant or a fishery) while taking into account species-specific variation in responses to the stressor (and in the case of the PSA, resilience to the impact). Information on trends is also important in evaluating whether management actions to diminish (or even stabilize) threat intensities may have been taken effectively, and this is treated elsewhere in the IEA.

In this update of the analysis on "Relative risk associated with non-fisheries threats to four focal groundfish species in the California Current" (Chapter 3 of the 2011 CCIEA), we have taken the approach of modifying the ecotoxicological/PSA approach taken last year (which was based on Samhouri and Levin, 2012) to more closely mimic the PSA approach with the goal of providing more useful and clear information on the relative risk imposed by the various non-fisheries threats to the four species in the California Current.

METHODS

FOCAL SPECIES

We re-examined the relative risk of 19 non-fisheries related threats to four groundfish species in the California current: Bocaccio (*Sebastes paucipinis*) and canary (*S. pinniger*) rockfish, Pacific hake (*Merluccius productus*), and sablefish (*Anoplopoma fimbria*). Each species is managed under the Pacific Fishery Management Council's (PFMC) groundfish Fishery Management Plan (FMP). There are over 90 species of groundfish managed under the FMP, and the four species we examined represent species of high value (Pacific hake and sablefish) and species that are of high concern due to depleted stock levels (bocaccio and canary rockfish). These four also cover a range of productivities, variability in recruitment, migratory behavior, habitat associations, longevities, and ages at maturity, and thus are reasonably representative of the variability of life history among groundfish in the CC. For each species we examined risk to both the juvenile and adult life-stages.

Bocaccio juveniles are generally associated with inshore benthic habitats, rocks with algae, and sandy zones with eelgrass or drift algae. Juveniles gradually shift to deeper high-relief rocky habitats at depths of ~50 – 250 m; however, max depths have been reported to 478 m (Love et al. 2002).

Canary rockfish juveniles are generally associated with benthic habitats, tide pools, kelp beds, and the interface between sand and rock outcrops at depths of ~15-20 m. Juveniles shift to deeper habitat at the end of the summer and adults are commonly found near pinnacles and high-relief rocky habitats with high currents at depths of ~80 – 200m with max depths to 838 m. Canary rockfish commonly school near but not on bottom (Love et al. 2002).

Pacific hake juveniles live in shallow coastal waters, bays, and estuaries (Bailey 1981, Bailey et al. 1982, Dark 1975, Dark and Wilkins 1994, Dorn 1995, NOAA 1990, Sakuma and Ralston 1995, Smith 1995), and move to deeper water as they get older (NOAA 1990). Pacific hake school at depth during the day, then move to the surface and disperse at night for feeding (McFarlane and Beamish 1986, Sumida and Moser 1980, Tanasich et al. 1991). Adults are epi-mesopelagic (Bailey et al. 1982, NOAA 1990, Sumida and Moser 1980). Highest densities of Pacific hake are usually found between 50 and 500 m, but adults occur as deep as 920 m and as far offshore as 400 km (Bailey 1982, Bailey et al. 1982, Dark and Wilkins 1994, Dorn 1995, Hart 1973, NOAA 1990, Stauffer 1985). Spawning is greatest at depths between 130 and 500 m (Bailey et al. 1982, NOAA 1990, Smith 1995).

As juveniles, sablefish are generally found in schools near surface offshore and then migrate to inshore waters after several months (Hart 1973). As sablefish mature, they migrate offshore and live near bottom at depths to 1500 m, but are most commonly found between 366 – 915 m (Hart 1973, Schirripa 2007).

NON-FISHERIES THREATS

We continue to focus on the 19 non-fisheries related threats used in Halpern et al (2009a): aquaculture, atmospheric deposition, coastal engineering, direct human impacts, inorganic pollution, light pollution, nutrient input, ocean-based pollution, offshore oil activity, organic pollution, power planets (here refered to as "coastal seawater exchange" so as to include desalination plants, etc.), sediment runoff decrease, sediment runoff increase, shipping activity, species invasions, coastal trash, ocean acidification, sea-surface temperature anomalies, and UV radiation (see Table GFR1). These data describe the relative spatial intensity of each threat within 1-km^2 grid cells of the California Current. Data were downloaded from the National Center for Ecological Analysis and Synthesis website (http://www.nceas.ucsb.edu/globalmarine/ca_current_data). Each threat is described in detail in Appendix GFR B and in the supporting material of Halpern et al (2008; 2009a).

This analysis represents an attempt to synthesize and describe spatial and temporal variation in the intensity of these threats as they relate to the four groundfish species. We have highlighted particular areas (data sources, etc.) which could be improved or enhanced given sufficient time.

OVERVIEW OF RISK CALCULATION

We assess the risk that various non-fisheries threats will lead to negative effects on the adult and juvenile populations of bocaccio, canary rockfish, sablefish, and Pacific hake within the U.S. borders of the California Current Large Marine Ecosystem. As was done last year, we evaluate risk, assuming management practices continue unchanged, based on two axes of information. However, we use different axes than were employed in that document. There, the two axes represented exposure to a threat and the sensitivity of a species/stage to that threat (from Samhouri and Levin, 2012). However, the sensitivity metric also included the intrinsic productivity of a species. The goal of risk analysis (according to NOAA Technical Memorandum NMFS-NWFSC-109, April 2011, p xvi) is "to fully explore the susceptibility of an indicator to natural or human threats, as well as the ability of the indicator to return to is previous state after being perturbed", i.e. to assess susceptibility and resilience (or productivity). Generally these two measures have been kept separate as they represent, respectively, the effect of the threat and the intrinsic resilience of the population. Here we return to the productivity-susceptibility (PSA) approach of assessing vulnerability as put forward by Patrick et al. (2009, 2010), applying this method to non-fisheries threats.

The first axis is related to the productivity *P* of a species, a value based on various life history traits of the species, such as fecundity and age at maturity. The second axis is related to the susceptibility *S* of the population to the threats. In Patrick et al. (2009, 2010), this had to do with susceptibility to fishing, but for this risk analysis it is calculated as the product of two other values, exposure (e) and sensitivity (s) to each threat. The final value for relative risk *R* to each species/life history stage was then calculated as

$$R_{ij} = \sqrt{P^2 + S^2} = \sqrt{P^2 + (e * s)^2}$$

Under this framework, the risk to a species increases with Euclidean distance from the origin and productivity and susceptibility received equivalent weight in estimating risk. This is the approach developed by Patrick et al. (2009, 2010), and provides a nice visualization of the relative components of risk for each threat (e.g. Figures GFR1-19), although since the Susceptibility score is currently a relative score, the risk is not generally comparable among threats. Nor have we attempted to calculate cumulative risk in this document.

Values of *P* and *s* for each species/life history stage are averages of several sub-scores, each based on standardized set of criteria. The value for *e* is a product of metrics of habitat suitability and threat intensity across the area of the California Current.

PRODUCTIVITY AXIS

Productivity *P* for each species was taken from Cope et al. (2011), which used a weighted average of 10 criteria (The intrinsic rate of population grown, *r*; maximum age; maximum size; the von Bertalanffy growth coefficient *k*; natural mortality rate *M*; fecundity; a metric of breeding strategy; a metric of temporal recruitment variability; age at maturity; and mean trophic level). Each criterion was designated 1, 2, or 3 (Table GFR2). Naturally, values for *P* varied only across species, not across life history stages within each species.

Eventually, the productivity axis could be expanded to reflect resilience to the particular threat including productivity and other factors specific to the particular threat being considered

SUSCEPTIBILITY AXIS

Susceptibility is calculated as the product of Exposure and Sensitivity. This is similar to the concept from Patrick et al. (2009; 2010) for fisheries susceptibility. In that case exposure can be thought of as the areal overlap of fishing and habitat along with the intensity of fishing, and sensitivity can be thought of as catchability and selectivity of the fisheries for that species, along with habitat impacts, etc. Here we have instead the areal overlap of the threat and the habitat for that species/stage, along with the intensity of the threat for exposure, while the sensitivity of the species/stage to the threat represents direct and indirect impacts to that species/stage.

EXPOSURE

The value for *e* is a measure of overlap between each species' spatial distribution and the relative intensity of each threat across the area of the California Current. For this calculation we took advantage of two published GIS data sets. The exposure values are the same as those in the previous CCIEA, except divided by 2 to get back to the simpler scale of 0 to 1.

First, we used Habitat Suitability Probabilities to describe the distribution of each species/life-history stage (Figs. 18-25). HSP values describe the probability of occurrence of each species/life history stage within the U.S. boundaries of the California Current. Briefly, the HSP values were calculated for the National Marine Fisheries Service (NMFS) Northwest Region and the Pacific Fishery Management Council in support of an Environmental Impact Statement (EIS) to consider the designation and conservation of Essential Fish Habitat (EFH) for Pacific Coast Groundfish (http://www.nwr.noaa.gov/Groundfish-Halibut/Groundfish-Fishery-Management/NEPA-Documents/EFH-Final-EIS.cfm). HSP values were generated from merged habitat and bathymetry GIS data and a Bayesian Network model that incorporated information about species' habitat preferences (bottom type and depth preferences) from NMFS trawl surveys and the Habitat Use Database (see Figures GFR20-27 and Appendix GFR A for more details). We used data if HSP values were ≥ 0.01 because HSP values for habitat < .01 were not retained during the modeling.

Second, we used data from Halpern et al (2009a) to describe the spatial intensity of each threat throughout the distribution of each species/life history stage. These data layers provide a relative score for the intensity of each threat (log-transformed and rescaled between 0 and 1) in 1-km^2 grid cells across the entire California Current. The data sources and calculations for each threat are described in detail in the supporting materials of Halpern et al (2008; 2009a), and briefly outlined in Appendix GFR B.

HSP data layers for each species/life history stage and the 19 threat data layers were brought into ArcView version 9.3 for analysis The HSP data layer was then multiplied by each threat data layer to calculate the exposure intensity (*ei*) for each threat across the distribution of each species/life history stage (Table GFR4). Thus, the threat *j* intensity scores were weighted by the probability of species/life history stage *i* occurring in each 1-km^2 cell. For each cell we then had

$$ei_{ij} = HSP_i * t_j$$

where t_j is the intensity (log-transformed and scaled 0-1) of threat *j* (Table GRF5).

For visual representation, we classified the distribution of ei_{ij} values into three terciles (high, medium, and low), although offshore oil activity data was divided into only high and low categories based on the median value because there were so few unique values.

For the final exposure score *e*, we summed all exposure intensity values for each species/life history stage *i*/threat *j*. We then scaled each sum between 0 and 1, with 1 corresponding to the sum of the HSP values for that species/life history stage (theoretically a measure of exposure if threat intensity were 1 everywhere). This is a slightly different approach than that taken in the last version of the CCIEA. There the exposure scores were rescaled between 1 and 3 (instead of 0-1) with the threat with the greatest summed exposure intensity score for each species/stage acting as the scaling factor, such that that threat would receive a 3 for that species/stage, even if the total exposure intensity score was less than the sum of the HSP values (whereas in the current approach, a value of 1 would only be achieved if the total exposure intensity score was equal to the sum of the HSP values. i.e. if the level was the same everywhere).

SENSITIVITY

Sensitivity criteria include one criterion that describes the mortality induced by a threat and two more that describe the behavioral and physiological responses to a threat. We used the definitions in Table GFR3 to score the criteria (Table GFR6). Scoring for these criteria was based on the primary literature and is addressed in detail in Appendix GFR B. These three criteria were then averaged (with mortality given twice the weight of the other two) for each threat for each species/life history stage to arrive at the final Sensitivity score *s* between 1 and 3 (Table GFR7). Again, this is different than the definition of Sensitivity from the last CCIEA. In that document, the impacts of each threat on the individuals within the population and the resilience of the population (productivity) were bundled together in "Sensitivity". However, in returning to the PSA concept, Productivity and Sensitivity scores are kept separate.

There are some rather large remaining issues with quantifying sensitivity. We do not have a direct link between the actual levels of the threat in the environment and the sensitivity of the species. Therefore, we cannot state what the true sensitivity is to the current level of threat, nor can we comfortably compare threats. The sensitivity score should be linked to either the maximum level of a threat (i.e. linked to a value of 1) or to some other consistent value across threats. We requested information on the maximum value observed for each of the threats from Halpern et al. (2009a), but they were unable to provide those values in time for this document. Future work should link the threat intensities and sensitivity as well as explore the suitability of using a log(x+1) transform for scaling the level of the threat.

RESULTS

EXPOSURE INTENSITY

The calculated exposure intensity index for each species/life-history stage/threat varied throughout the distribution of each species for most threats. As examples, Figures GFR28 – 46 show the exposure intensity for Pacific hake adults for each of the 19 threats. There are several threats that show very little overlap with hake adult habitats, e.g. aquaculture (fish farms), coastal engineering, direct human impacts (trampling), offshore oil activities, coastal seawater exchange, and coastal trash (Figures GFR28, 30, 31, 36, 38, & 43, respectively). Spatially expansive threats affect nearly the entire distribution of adult hake, e.g. atmospheric deposition, ocean-based pollution, shipping, and the three climate change threats – ocean acidification, sea surface temperature, and UV radiation (Figures GFR29, 35, 41, 44 – 46, respectively). Threats that occur as point-sources show relatively high exposure intensity in coastal areas and low or no exposure in offshore portions of their distribution, e.g. inorganic pollution, light pollution, nutrient input, organic pollution, sediment runoff decrease and increase, and species invasions (Figures GFR32 – 34, 37, 39 – 40, and 42, respectively).

Across species/life history stages, exposure intensity generally varies in relation to the offshore distribution of adult habitats and the nearshore concentration of juvenile habitats. Thus, juveniles of most species tend to be exposed to higher intensities of point-source threats because of their higher probabilities of occurrence in nearshore habitats, while adults tend to have much broader exposure to spatially expansive threats, such as atmospheric deposition or the climate change threats. One generality among these four species may be that in the waters off Oregon and Washington, we found higher exposure intensities for juveniles as a result of their nearshore habitat, while adults experience broader, higher exposure intensities in waters off California due to broader habitat occurrence (compare Figures GFR47 & 48, 49 & 50, and 52 & 53).

RELATIVE RISK

In general, the current work indicates that the most spatially expansive threats are more likely to be of greater relative risk to each of the four species than threats related to point-sources (Figures GFR1-19). However, without a real link between the current and anticipated levels of the threat and the impacts, these results only indicate expansiveness/overlap of each threat, and not the actual potential impact.

CONCLUSIONS

Our analysis builds on the risk assessment framework of others and that of last year's CCIEA, making progress towards a method that will allow for comparison of relative risk among multiple non-fisheries threats, and potentially cumulative risk across threats. This framework will show which threats are relevant to focal species and provides a basis for prioritizing which threats are in need of management actions. Rapid assessments of other species can then be easily integrated into this framework.

Future versions of the CCIEA should further build upon this work by linking the actual current and anticipated threat exposure levels to the associated sensitivity scores, considering factors other than productivity in evaluating the resilience of a population to the effects of various threats, exploring the appropriateness of the log(x+1) transformation used before standardizing the exposure on a 0-1 scale for each threat.

Table GFR1. List of non-fisheries threats considered.

Threats
Aquaculture
Atmospheric deposition
Coastal engineering
Direct human impacts
Inorganic pollution
Light pollution
Nutrient input
Ocean-based pollution
Organic pollution
Offshore oil activities
Coastal seawater exchange
Sediment decrease
Sediment increase
Shipping activity
Species invasions
Coastal Trash

Table GFR2. Raw and final Productivity scores. A weighted average of the ten scores (Cope et al. 2011) is used, for final values ranging between 1 and 3. Boc = bocaccio *Sebastes paucispinis*; Can = canary rockfish *Sebastes pinniger*; Hake = Pacific hake *Merluccius productus*; Sable = Sablefish *Anoplopoma fimbria*; Ad = adult; Juv = juvenile.

Factor	**Weight**	**Boc Ad**	**Boc Juv**	**Can Ad**	**Can Juv**	**Hake Ad**	**Hake Juv**	**Sable Ad**	**Sable Juv**
r	**2**	1	1	1	1	1.5	1.5	1.5	1.5
Max age	**2**	1	1	1	1	2	2	1	1
Max size	**1**	2	2	2	2	2	2	2	2
k	**2**	1	1	1.5	1.5	3	3	2.5	2.5
M	**2**	1	1	1	1	2	2	1	1
Fecundity	**1**	3	3	3	3	3	3	3	3
Breeding strategy	**2**	1	1	1	1	3	3	3	3
Recruitment variability	**2**	1	1	1.5	1.5	1	1	1	1
Age at Maturity	**2**	2	2	1	1	2	2	1	1
Trophic level	**2**	1	1	1	1	1	1	1	1
Weighted Average (1-3)		1.28	1.28	1.28	1.28	2.00	2.00	1.61	1.61

Table GFR3. Definitions and scoring bins for the exposure and sensitivity criteria used in the risk assessment. Note that either 2 or alt2 and either 3 or alt3 are used.

Criteria	Explanation of criteria	Exposure/Sensitivity scores		
Exposure: Spatial intensity	The overlap between the probability of species occurrence (HSP) and the relative intensity of a threat.	Standardized distribution (scale=1-3) of the sum of species-specific exposure intensity values.		
Sensitivity Factors:		Low (1)	Moderate(2)	High(3)
1. Mortality (weight = 2)	Direct effect of threat on population-wide average mortality rate of a species	Negligible	Sub-lethal	Lethal
2. Behavioral response (weight =1)	Population-wide effect of threat on behavior of a species	Negligible behavioral response	Moderate behavioral response	Severe behavioral response
Alt 2. Effect of behavioral response (weight =1)	Population-wide change in sensitivity to threat due to behavioral response	Response reduces sensitivity	Response does not change sensitivity	Response increases sensitivity
3. Physiological response (weight =1)	Population-wide effect of threat on behavior or physiology of a species	Negligible physiological response	Moderate physiological response	Severe physiological response
Alt 3. Effect of physiological response (weight = 1)	Population-wide change in sensitivity to threat due to physiological response	Response reduces sensitivity	Response does not change sensitivity	Response increases sensitivity

Table GFR4. Summed Exposure intensities. Boc = bocaccio *Sebastes paucispinis*; Can = canary rockfish *Sebastes pinniger*; Hake = Pacific hake *Merluccius productus*; Sable = Sablefish *Anoplopoma fimbria*; Ad = adult; Juv = juvenile.

Threat	Boc Ad	Boc Juv	Can Ad	Can Juv	Hake Ad	Hake Juv	Sable Ad	Sable Juv
Aquaculture	0	0	0	0	2	0	2	0
Atmospheric deposition	2,866	9,481	4,180	11,092	42,572	55	70,199	25,431
Coastal engineering	2	105	2	263	377	0	224	11
Direct human impacts	1	121	1	100	170	0	63	51
Inorganic pollution	143	935	202	1,505	1,977	7	1,142	421
Light pollution	173	913	189	1,859	2,657	7	2,549	681
Nutrient input	473	2,482	883	3,629	5,100	14	3,221	1,597
Ocean-based pollution	1,314	4,525	2,081	6,678	14,625	19	18,549	6,883
Offshore oil activities	1	2	1	6	6	0	4	0
Organic pollution	416	2,568	969	3,743	4,838	10	2,737	1,488
Coastal seawater exchange	2	30	2	51	43	0	25	0
Sediment decrease	689	3,332	1,282	5,095	7,562	18	5,450	2,427
Sediment increase	1,786	7,384	3,298	10,506	16,773	18	11,868	5,975
Shipping activity	6	254	8	397	2,359	0	132	89
Species invasions	932	4,231	1,443	5,359	10,043	16	6,715	3,327
Coastal trash	3	219	3	408	266	1	94	41
Ocean Acidification	4,579	12,840	7,778	20,410	59,300	65	104,895	36,161
Sea Surface Temperature	2,352	8,710	4,947	10,870	32,291	38	49,054	20,411
UV radiation	4,411	12,526	7,354	19,374	57,542	66	100,313	34,891

Table GFR5. Final Exposure scores after sums of exposure intensity values were standardized by dividing by the estimated total suitable habitat (the sum of habitat suitability probabilities (HSP)) to get a value between 0 and 1. Boc = bocaccio *Sebastes paucispinis*; Can = canary rockfish *Sebastes pinniger*; Hake = Pacific hake *Merluccius productus*; Sable = Sablefish *Anoplopoma fimbria*; Ad = adult; Juv = juvenile.

Threat	Boc Ad	Boc Juv	Can Ad	Can Juv	Hake Ad	Hake Juv	Sable Ad	Sable Juv
Aquaculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Atmospheric deposition	0.53	0.62	0.45	0.45	0.61	0.72	0.57	0.60
Coastal engineering	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00
Direct human impacts	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Inorganic pollution	0.03	0.06	0.02	0.06	0.03	0.09	0.01	0.01
Light pollution	0.03	0.06	0.02	0.08	0.04	0.09	0.02	0.02
Nutrient input	0.09	0.16	0.09	0.15	0.07	0.18	0.03	0.04
Ocean-based pollution	0.24	0.30	0.22	0.27	0.21	0.25	0.15	0.16
Offshore oil activities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Organic pollution	0.08	0.17	0.10	0.15	0.07	0.13	0.02	0.04
Coastal seawater exchange	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sediment decrease	0.13	0.22	0.14	0.21	0.11	0.24	0.04	0.06
Sediment increase	0.33	0.48	0.35	0.43	0.24	0.24	0.10	0.14
Shipping activity	0.00	0.02	0.00	0.02	0.03	0.00	0.00	0.00
Species invasions	0.17	0.28	0.15	0.22	0.14	0.21	0.05	0.08
Coastal trash	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.00
Ocean Acidification	0.84	0.84	0.83	0.83	0.85	0.85	0.86	0.86
Sea Surface Temperature	0.43	0.57	0.53	0.44	0.46	0.50	0.40	0.48
UV radiation	0.81	0.82	0.79	0.79	0.82	0.86	0.82	0.83

Table GFR6. Raw Sensitivity scores based on literature review (see Table GFR1 for definitions of factors and scoring bins; see Appendix GFR B for details and rationale for scoring). Boc = bocaccio *Sebastes paucispinis*; Can = canary rockfish *Sebastes pinniger*; Hake = Pacific hake *Merluccius productus*; Sable = Sablefish *Anoplopoma fimbria*; Ad = adult; Juv = juvenile.

Criterion	Boc Ad	Boc Juv	Can Ad	Can Juv	Hake Ad	Hake Juv	Sable Ad	Sable Juv
1. Mortality								
Aquaculture	1	1	1	1	1	1	1	1
Atmospheric deposition	2	3	2	3	2	3	2	3
Coastal engineering	1	1	1	1	1	1	1	1
Direct human impacts	1	1	1	1	1	1	1	1
Inorganic pollution	2	3	2	3	2	3	2	3
Light pollution	1	1	1	1	1	1	1	1
Nutrient input	1	2	1	2	1	2	1	2
Ocean-based pollution	2	2	2	2	2	2	2	2
Offshore oil activities	1	1	1	1	1	1	1	1
Organic pollution	2	3	2	3	2	3	2	3
Coastal seawater exchange	1	3	1	3	1	3	1	3
Sediment decrease	1	1	1	1	1	1	1	1
Sediment increase	2	2	2	2	2	2	2	2
Shipping activity	1	1	1	1	1	1	1	1
Species invasions	2	3	2	3	2	3	2	3
Coastal trash	2	2	2	2	2	2	2	2
Ocean Acidification	2	3	2	3	2	3	2	3
Sea Surface Temperature	2	2	2	2	2	2	2	2
UV radiation	1	2	1	2	1	2	1	2
2. Behavioral response								
Aquaculture	3	3	3	3	2	2	2	2
Atmospheric deposition	2	2	2	2	2	2	2	2
Coastal engineering	3	3	3	3	2	2	1	2
Direct human impacts	1	1	1	1	1	1	1	1
Inorganic pollution	2	2	2	2	2	2	2	2
Light pollution	2	2	2	2	2	2	1	1
Nutrient input	1	1	1	1	1	1	1	1
Ocean-based pollution	3	3	3	3	2	2	2	2
Offshore oil activities	3	3	3	3	2	2	1	2

Criterion	Boc Ad	Boc Juv	Can Ad	Can Juv	Hake Ad	Hake Juv	Sable Ad	Sable Juv
Organic pollution	2	2	2	2	2	2	2	2
Coastal seawater exchange	2	3	2	3	2	2	2	2
Sediment decrease	1	1	1	1	2	2	1	2
Sediment increase	1	1	1	1	2	2	1	2
Shipping activity	2	2	2	2	2	2	2	2
Species invasions	3	3	3	3	3	3	3	3
Coastal trash	3	3	3	3	2	2	1	2
Ocean Acidification	3	3	3	3	3	3	3	3
Sea Surface Temperature	3	3	3	3	1	1	1	1
UV radiation	1	2	1	2	2	2	1	1
3. Physiological response								
Aquaculture	2	2	2	2	2	2	2	2
Atmospheric deposition	3	2	3	2	3	2	3	2
Coastal engineering	2	2	2	2	2	2	2	2
Direct human impacts	2	2	2	2	2	2	2	2
Inorganic pollution	3	2	3	2	3	2	3	2
Light pollution	2	2	2	2	2	2	2	2
Nutrient input	2	2	2	2	2	2	2	2
Ocean-based pollution	2	2	2	2	2	2	2	2
Offshore oil activities	2	2	2	2	2	2	2	2
Organic pollution	3	2	3	2	3	2	3	2
Coastal seawater exchange	2	2	2	2	2	2	2	2
Sediment decrease	2	2	2	2	2	2	2	2
Sediment increase	2	2	2	2	2	2	2	2
Shipping activity	2	2	2	2	2	2	2	2
Species invasions	2	2	2	2	2	2	2	2
Coastal trash	2	2	2	2	2	2	2	2
Ocean Acidification	2	2	2	2	2	2	2	2
Sea Surface Temperature	3	3	3	3	2	2	2	2
UV radiation	1	1	1	1	1	1	1	1

Table GFR7. Final Sensitivity scores: The weighted average of the across the three sensitivity criteria (with mortality given twice the weight of the other two) to get a value between 1 and 3. Boc = bocaccio *Sebastes paucispinis*; Can = canary rockfish *Sebastes pinniger*; Hake = Pacific hake *Merluccius productus*; Sable = Sablefish *Anoplopoma fimbria*; Ad = adult; Juv = juvenile.

Threat	Boc Ad	Boc Juv	Can Ad	Can Juv	Hake Ad	Hake Juv	Sable Ad	Sable Juv
Aquaculture	1.75	1.75	1.75	1.75	1.50	1.50	1.50	1.50
Atmospheric deposition	2.25	2.50	2.25	2.50	2.25	2.50	2.25	2.50
Coastal engineering	1.75	1.75	1.75	1.75	1.50	1.50	1.25	1.50
Direct human impacts	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Inorganic pollution	2.25	2.50	2.25	2.50	2.25	2.50	2.25	2.50
Light pollution	1.50	1.50	1.50	1.50	1.50	1.50	1.25	1.25
Nutrient input	1.25	1.75	1.25	1.75	1.25	1.75	1.25	1.75
Ocean-based pollution	2.25	2.25	2.25	2.25	2.00	2.00	2.00	2.00
Offshore oil activities	1.75	1.75	1.75	1.75	1.50	1.50	1.25	1.50
Organic pollution	2.25	2.50	2.25	2.50	2.25	2.50	2.25	2.50
Coastal seawater exchange	1.50	2.75	1.50	2.75	1.50	2.50	1.50	2.50
Sediment decrease	1.25	1.25	1.25	1.25	1.50	1.50	1.25	1.50
Sediment increase	1.75	1.75	1.75	1.75	2.00	2.00	1.75	2.00
Shipping activity	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Species invasions	2.25	2.75	2.25	2.75	2.25	2.75	2.25	2.75
Coastal trash	2.25	2.25	2.25	2.25	2.00	2.00	1.75	2.00
Ocean Acidification	2.25	2.75	2.25	2.75	2.25	2.75	2.25	2.75
Sea Surface Temperature	2.50	2.50	2.50	2.50	1.75	1.75	1.75	1.75
UV radiation	1.00	1.75	1.00	1.75	1.25	1.75	1.00	1.50

Table GFR8. Final Susceptibility scores: Exposure multiplied by Sensitivity to get a value between 0 and 2. Boc = bocaccio *Sebastes paucispinis*; Can = canary rockfish *Sebastes pinniger*; Hake = Pacific hake *Merluccius productus*; Sable = Sablefish *Anoplopoma fimbria*; Ad = adult; Juv = juvenile.

Threat	Boc Ad	Boc Juv	Can Ad	Can Juv	Hake Ad	Hake Juv	Sable Ad	Sable Juv
Aquaculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Atmospheric deposition	0.66	0.93	0.56	0.68	0.76	1.08	0.72	0.90
Coastal engineering	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Direct human impacts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inorganic pollution	0.03	0.09	0.03	0.09	0.04	0.14	0.01	0.01
Light pollution	0.02	0.03	0.01	0.04	0.02	0.05	0.01	0.00
Nutrient input	0.02	0.12	0.02	0.11	0.02	0.14	0.01	0.03
Ocean-based pollution	0.30	0.37	0.28	0.34	0.21	0.25	0.15	0.16
Offshore oil activities	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Organic pollution	0.10	0.25	0.13	0.23	0.09	0.20	0.03	0.05
Coastal seawater exchange	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sediment decrease	0.03	0.05	0.03	0.05	0.05	0.12	0.01	0.03
Sediment increase	0.25	0.36	0.27	0.32	0.24	0.24	0.07	0.14
Shipping activity	0.00	0.01	0.00	0.01	0.02	0.00	0.00	0.00
Species invasions	0.21	0.49	0.19	0.38	0.18	0.37	0.07	0.14
Coastal trash	0.00	0.02	0.00	0.02	0.00	0.01	0.00	0.00
Ocean Acidification	1.05	1.48	1.04	1.45	1.06	1.49	1.07	1.50
Sea Surface Temperature	0.65	0.86	0.80	0.66	0.35	0.37	0.30	0.36
UV radiation	0.00	0.62	0.00	059	0.21	0.65	0.00	0.41

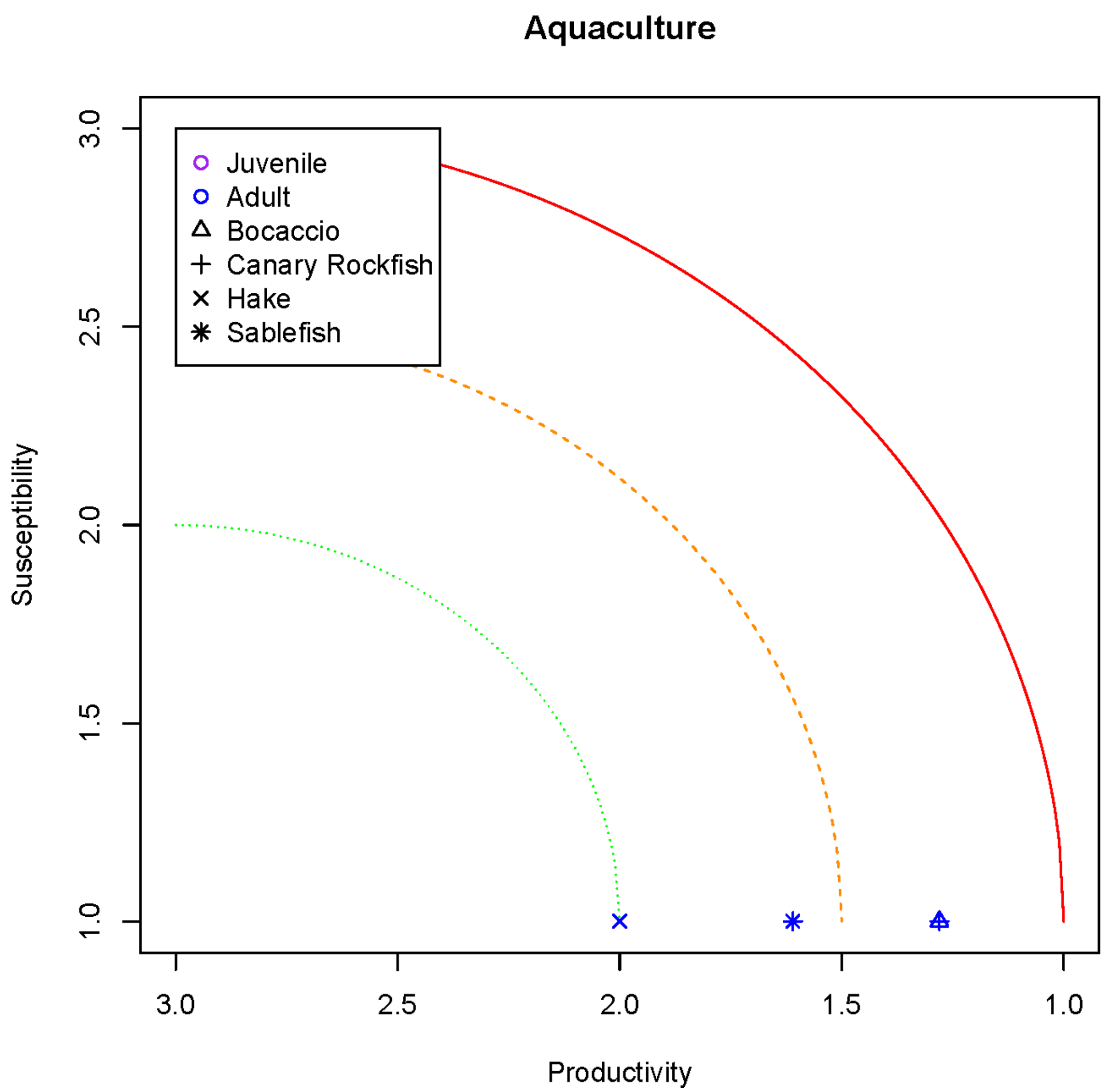

Figure GFR1. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to aquaculture as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

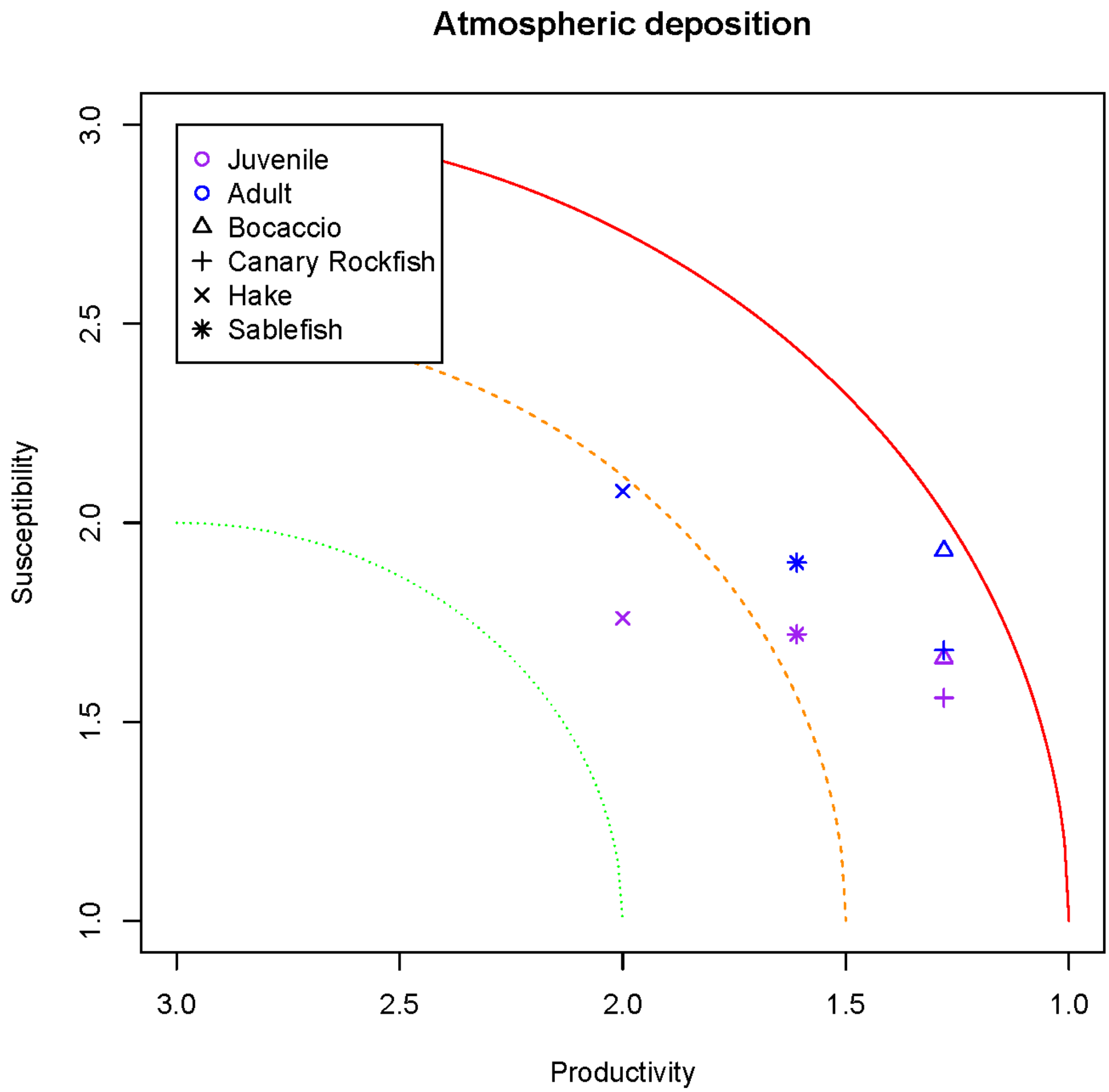

Figure GFR2. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to atmospheric deposition as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

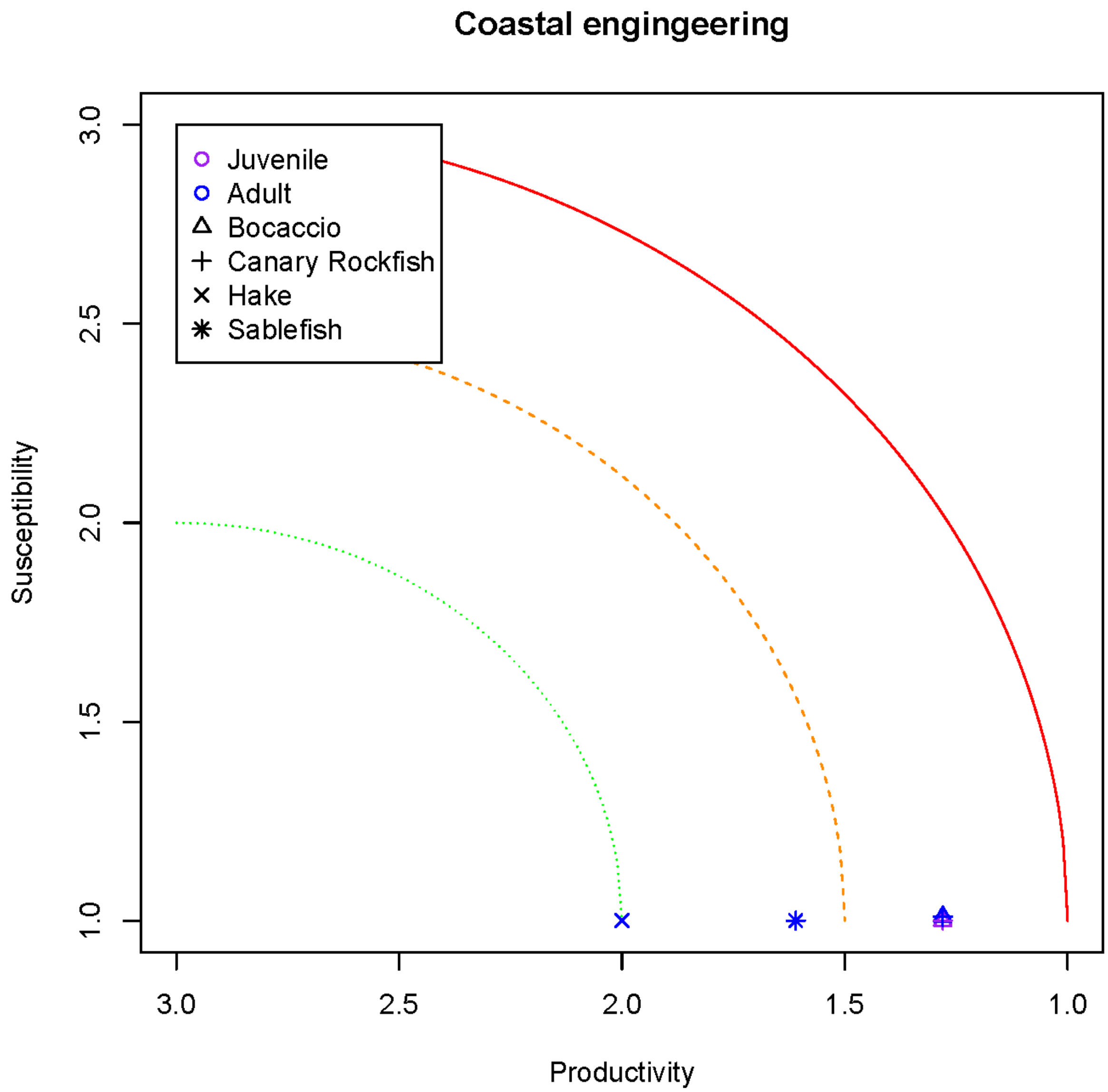

Figure GFR3. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to coastal engineering as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

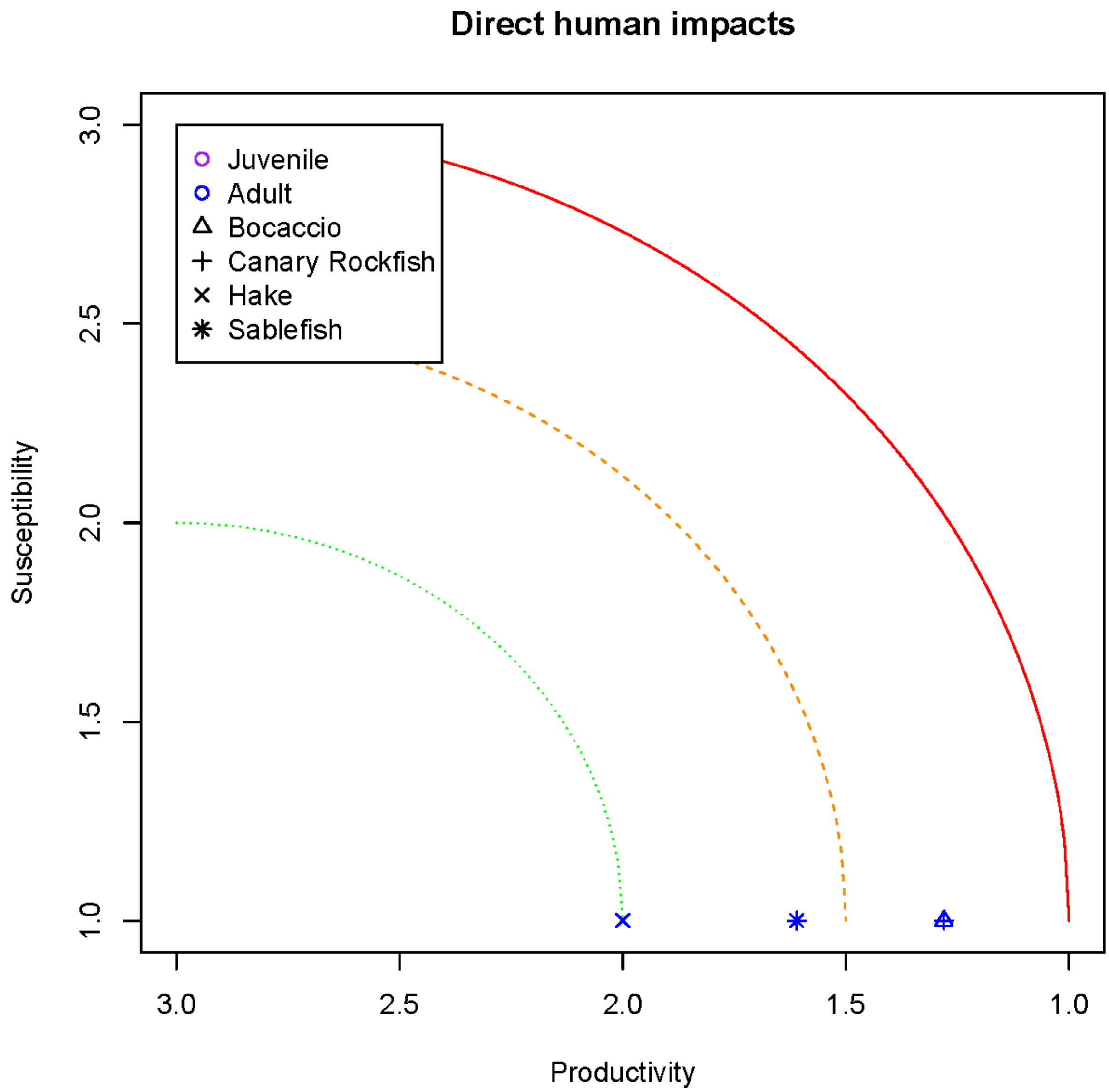

Figure GFR4. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to direct human impacts as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

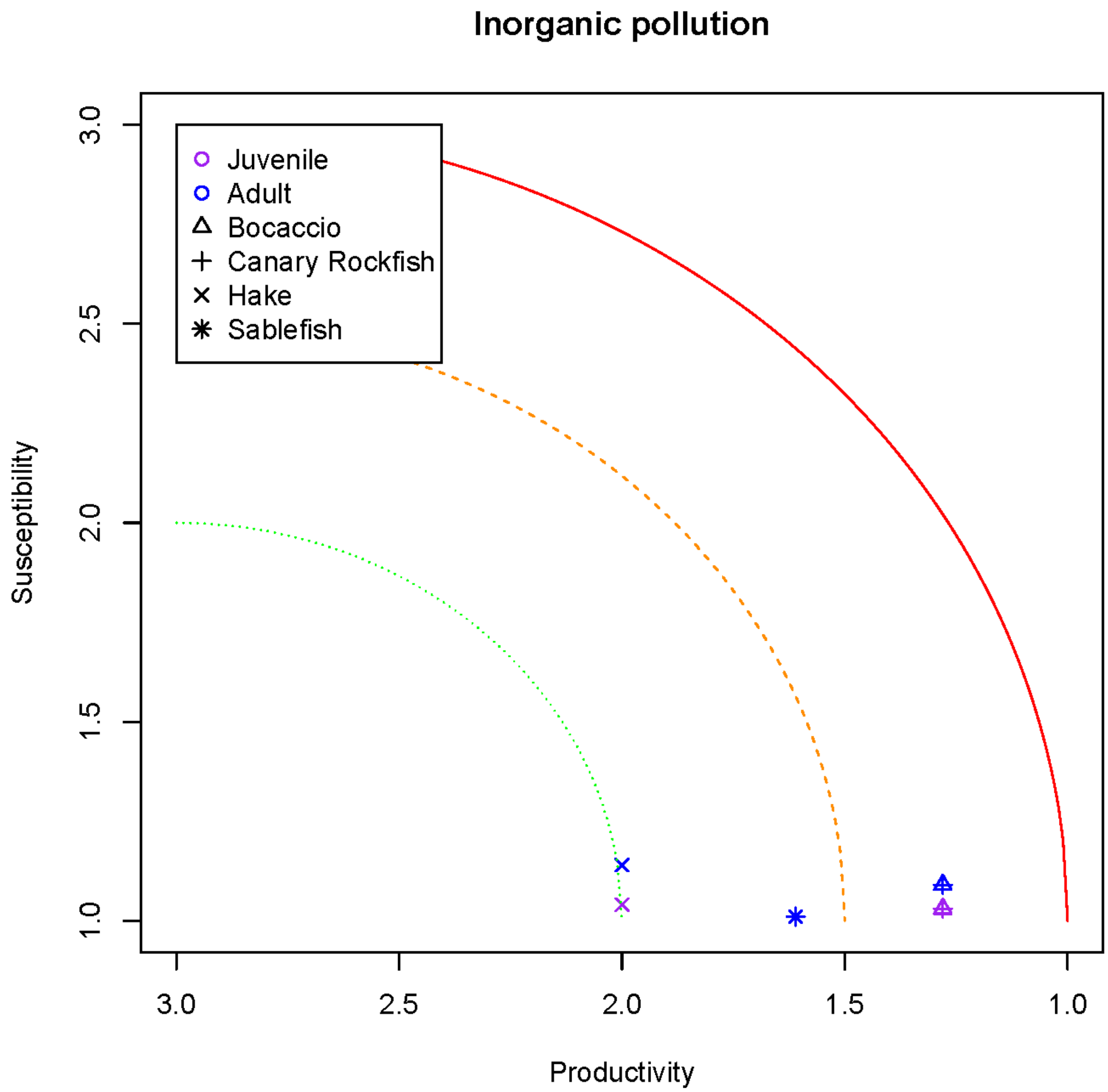

Figure GFR5. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to inorganic pollution as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

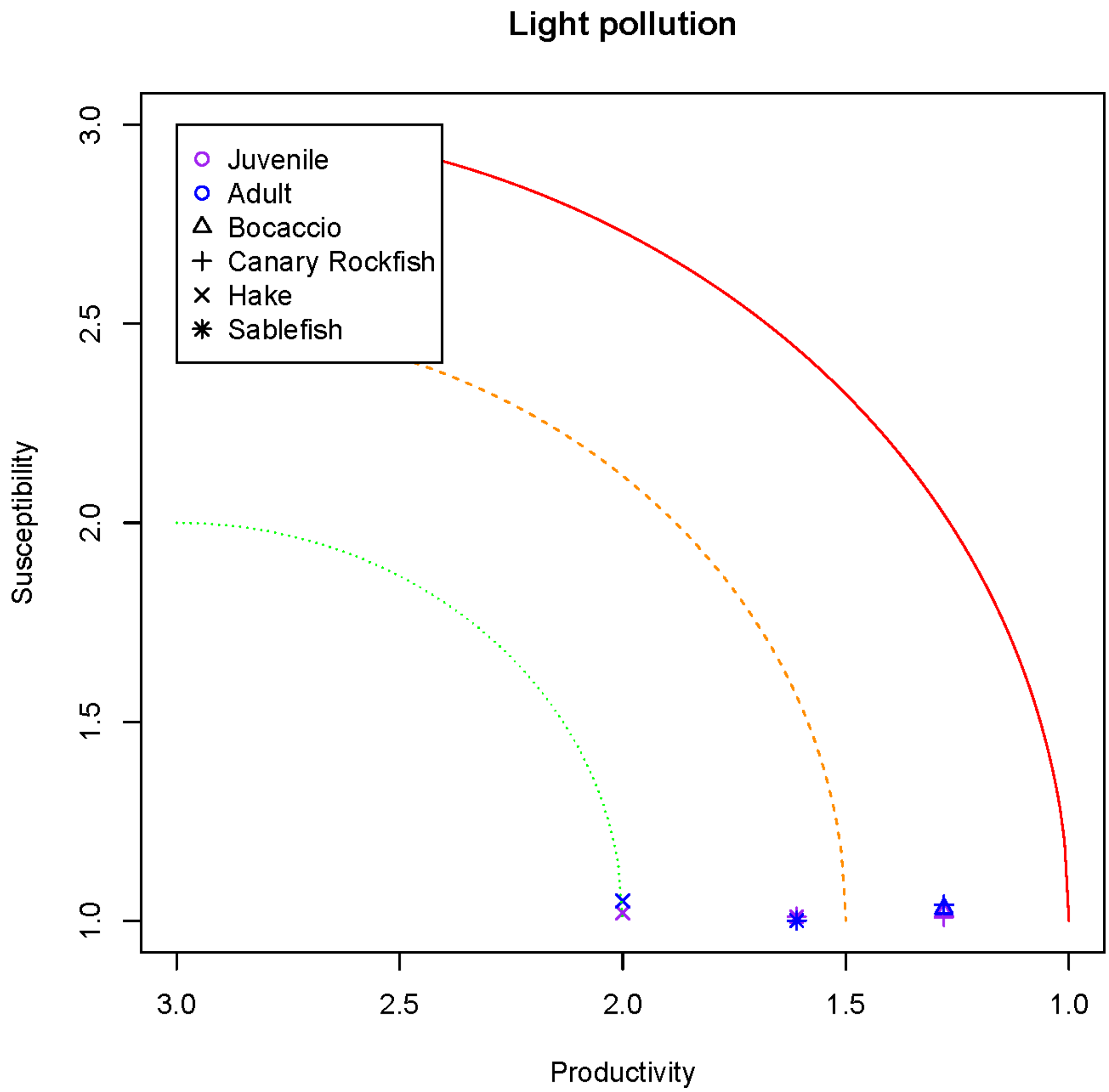

Figure GFR6. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to light pollution as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

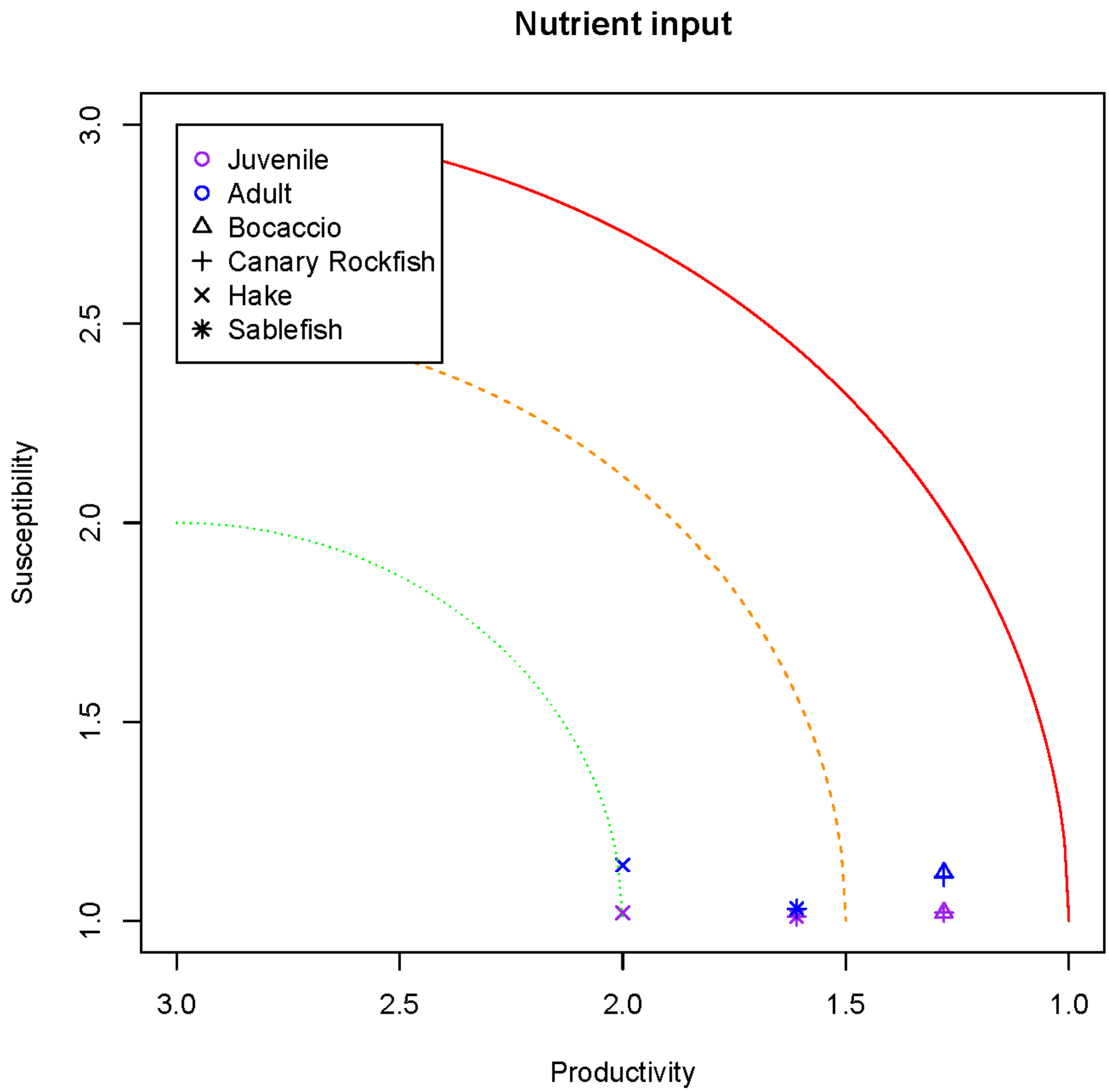

Figure GFR7. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to nutrient input as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

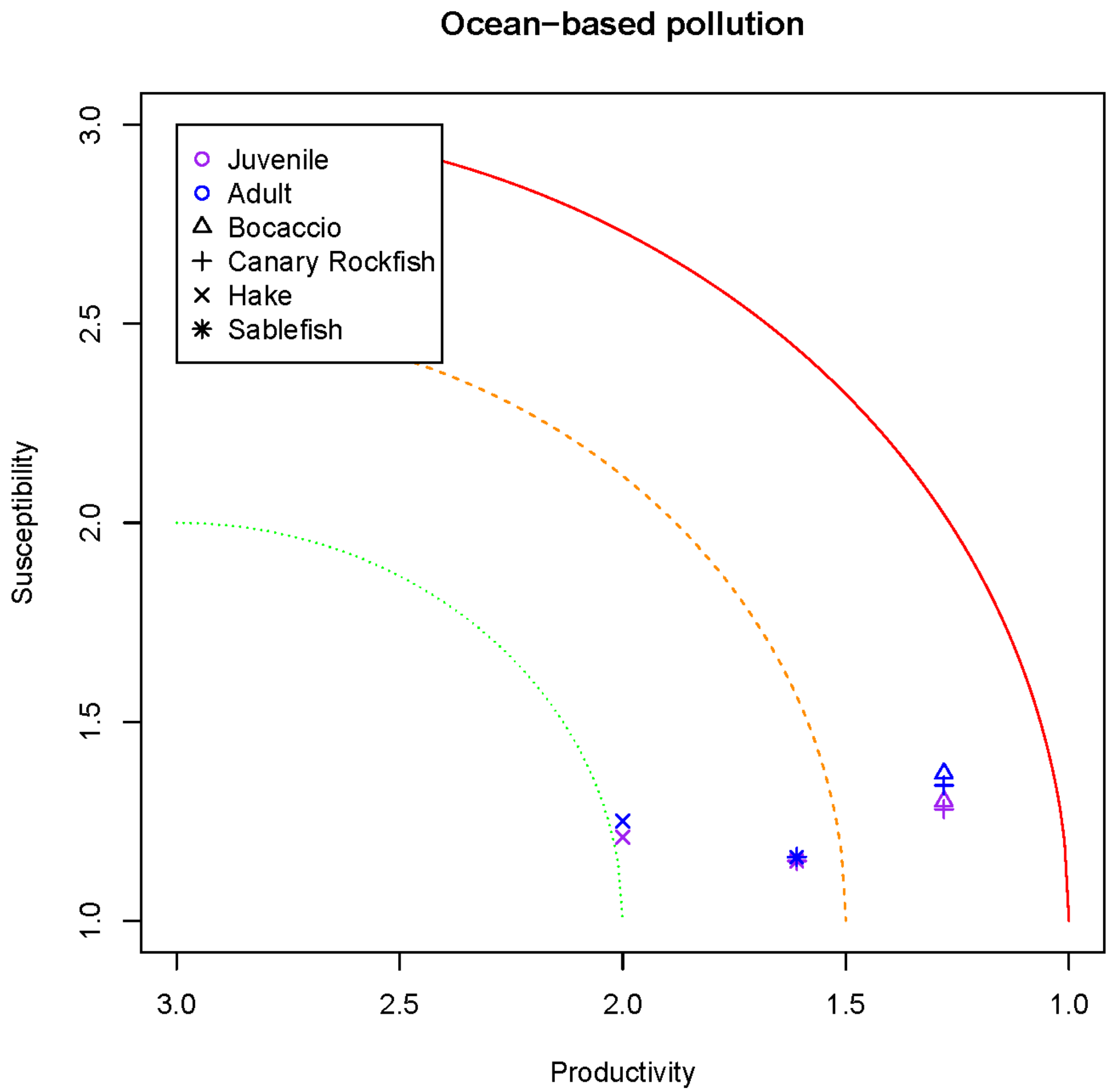

Figure GFR8. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to ocean based pollution as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

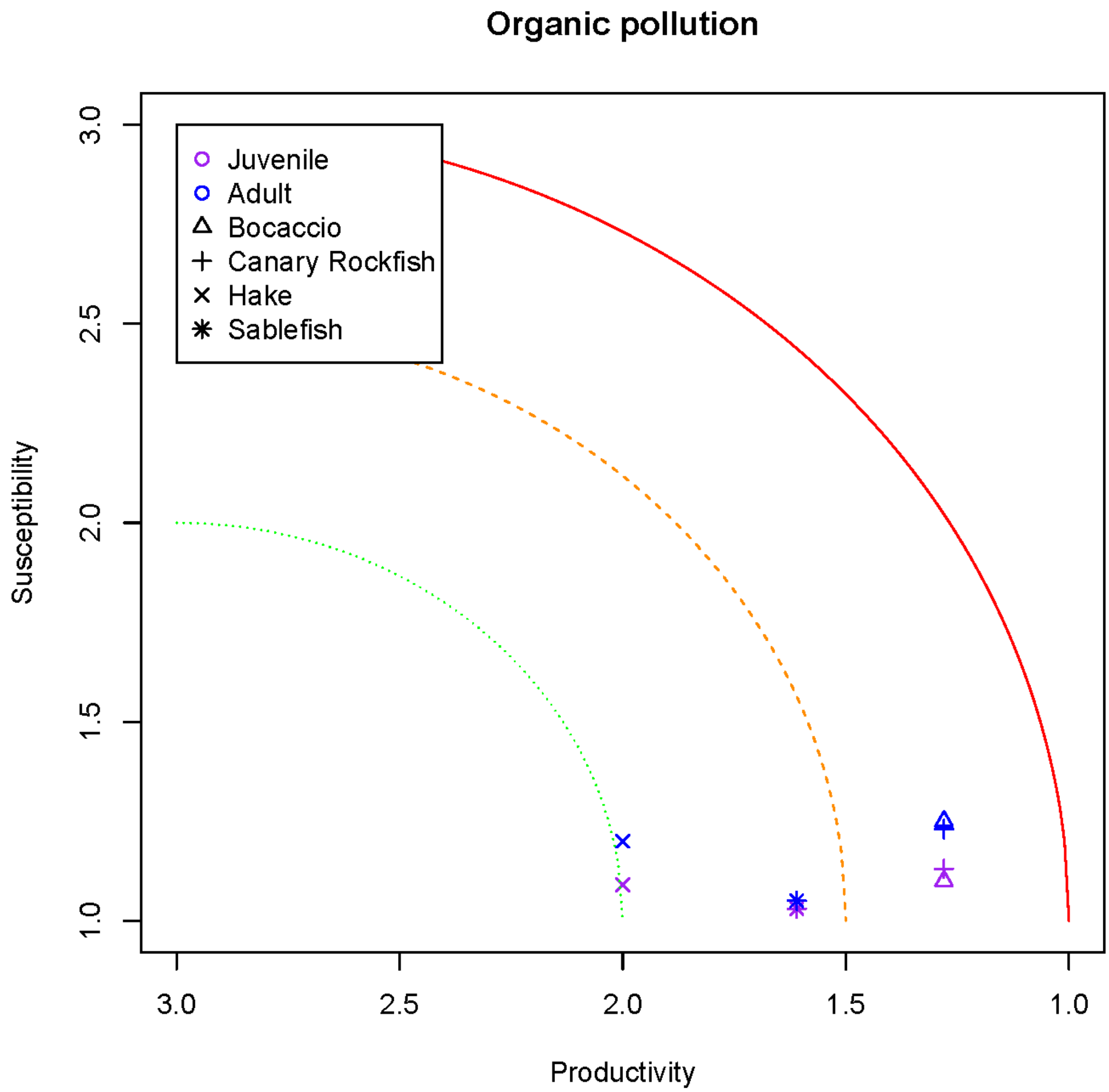

Figure GFR9. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to organic pollution as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

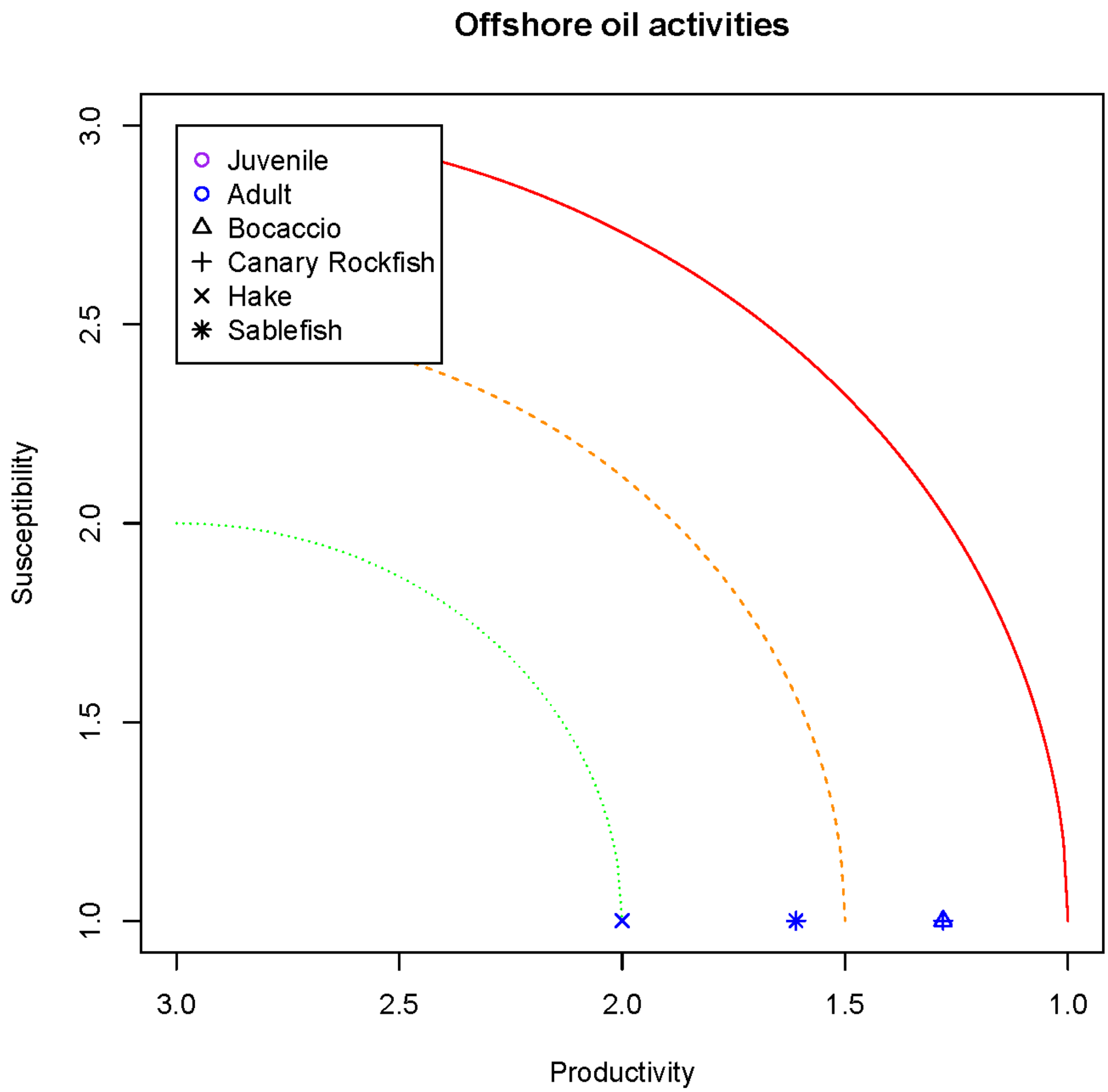

Figure GFR10. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to offshore oil activities as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

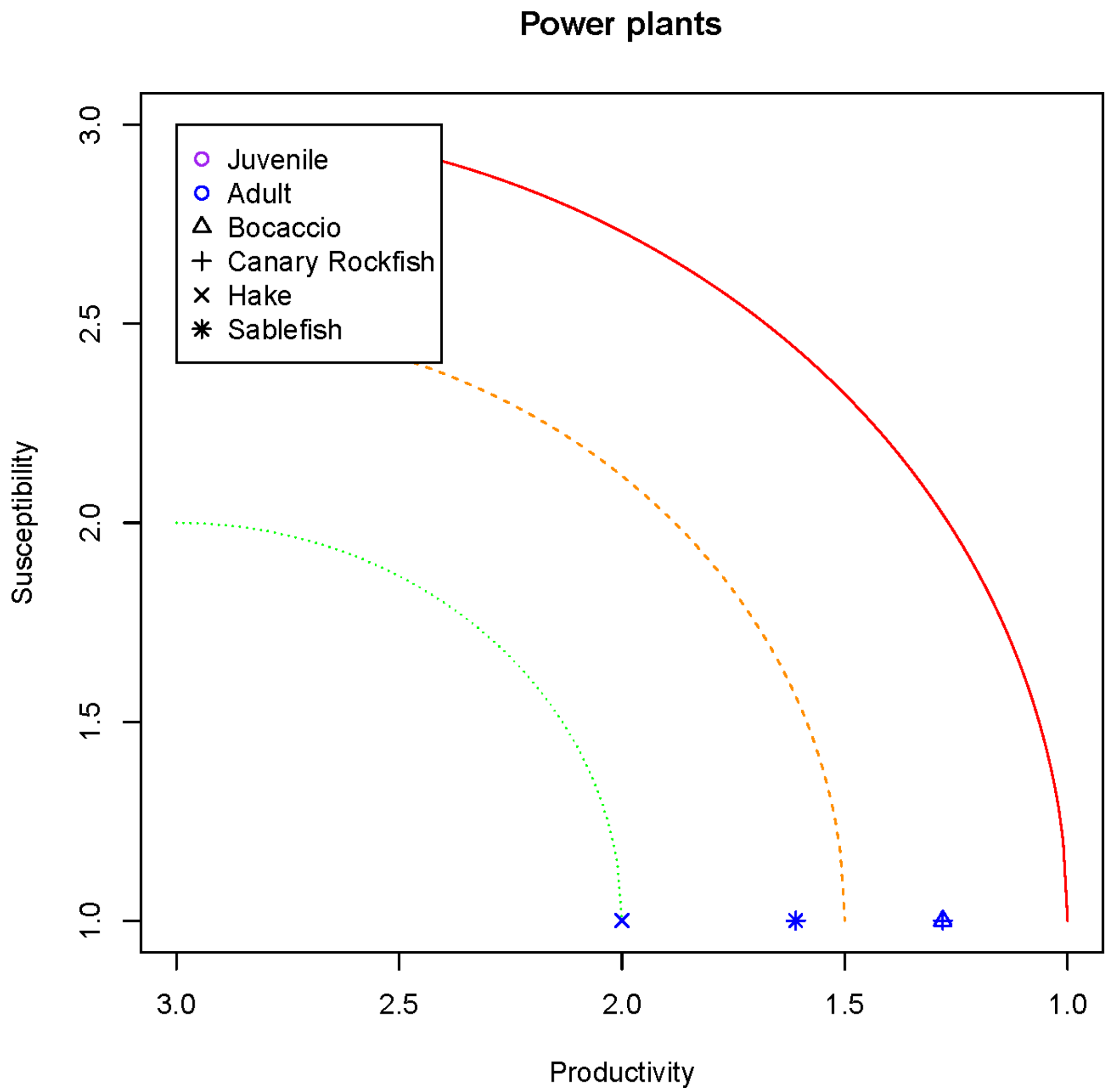

Figure GFR11. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to coastal seawater exchange (including power plants) as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

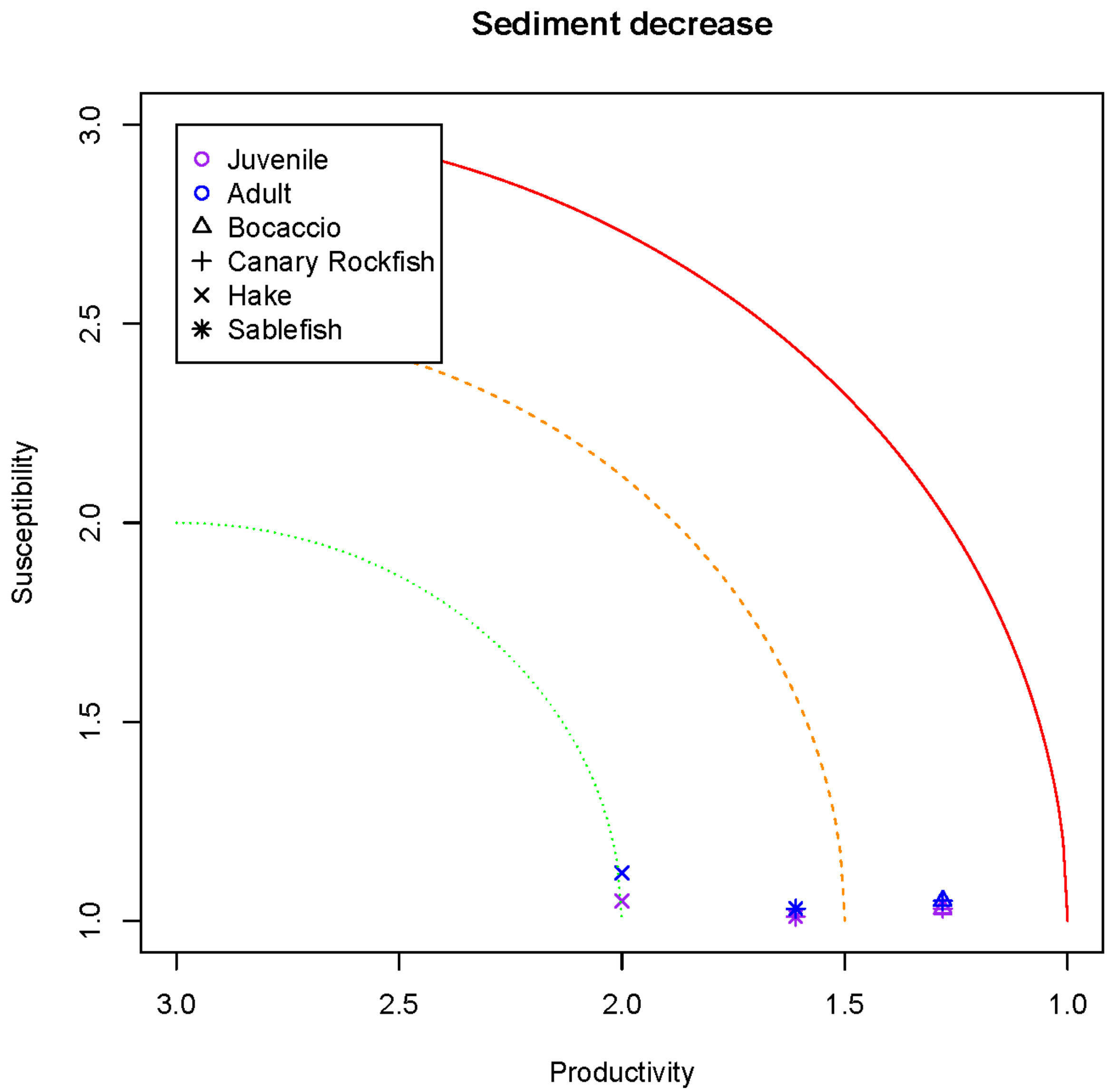

Figure GFR12. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to sediment decrease as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

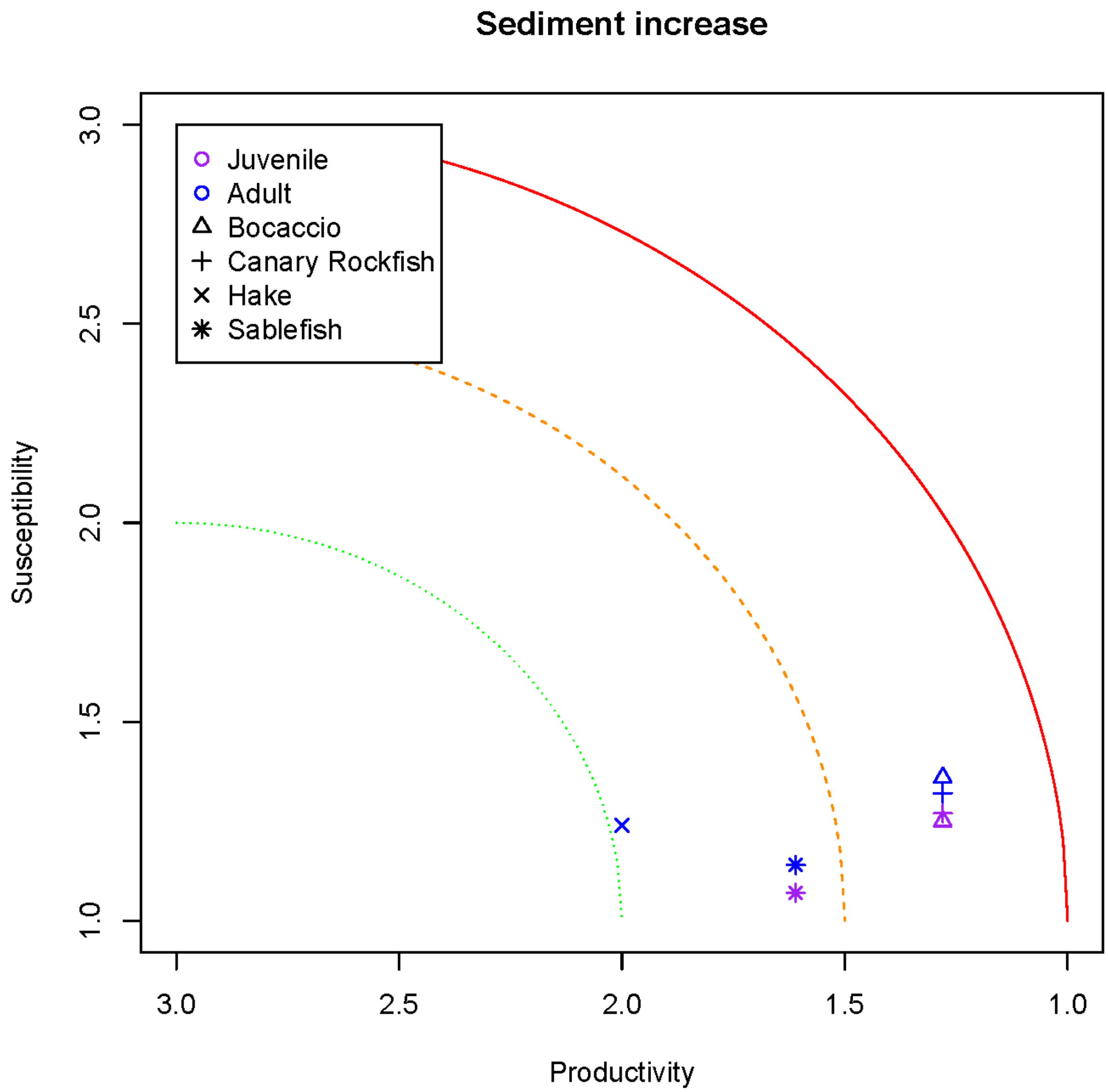

Figure GFR13. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to sediment increase as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

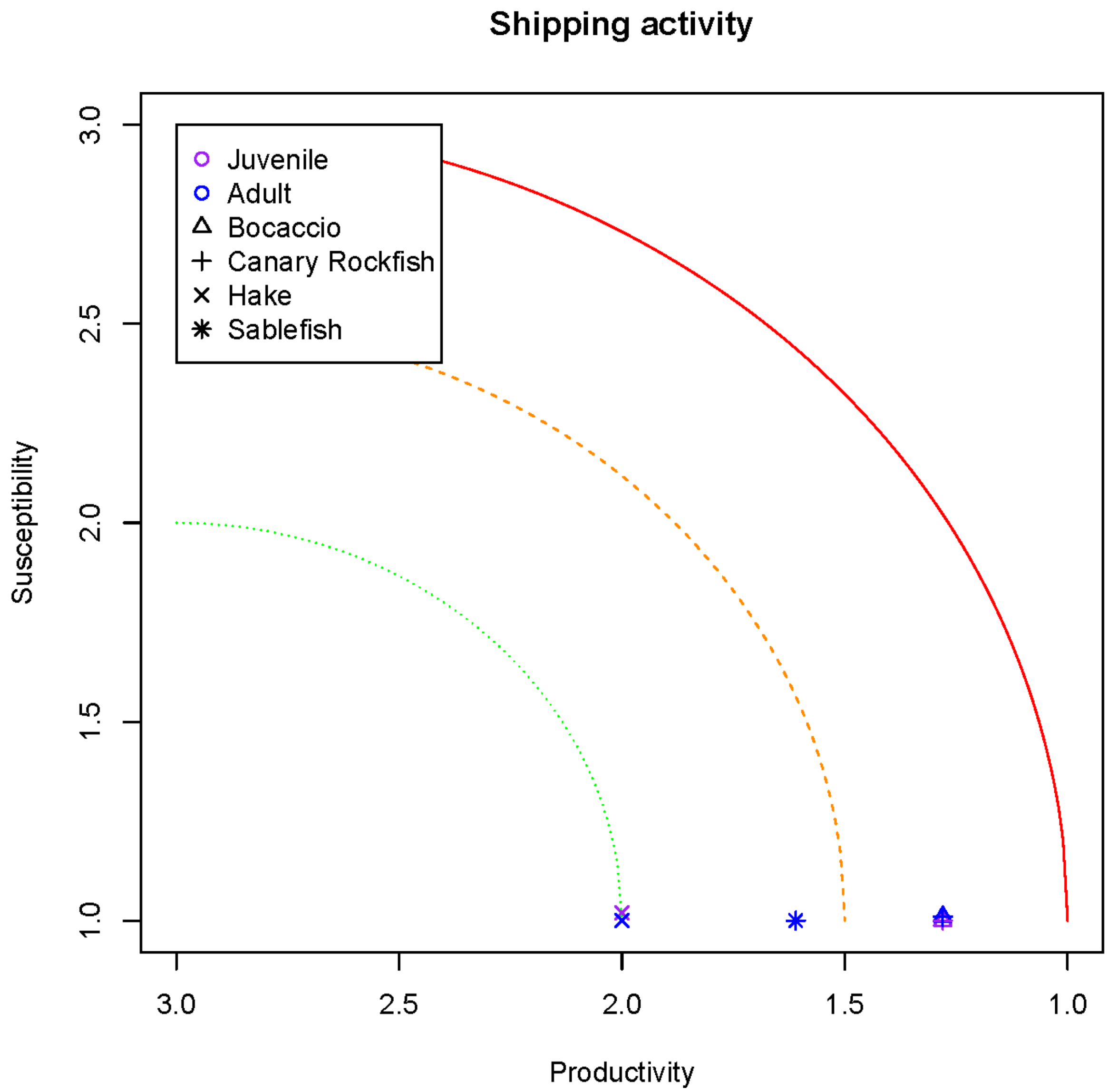

Figure GFR14. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to shipping activity as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

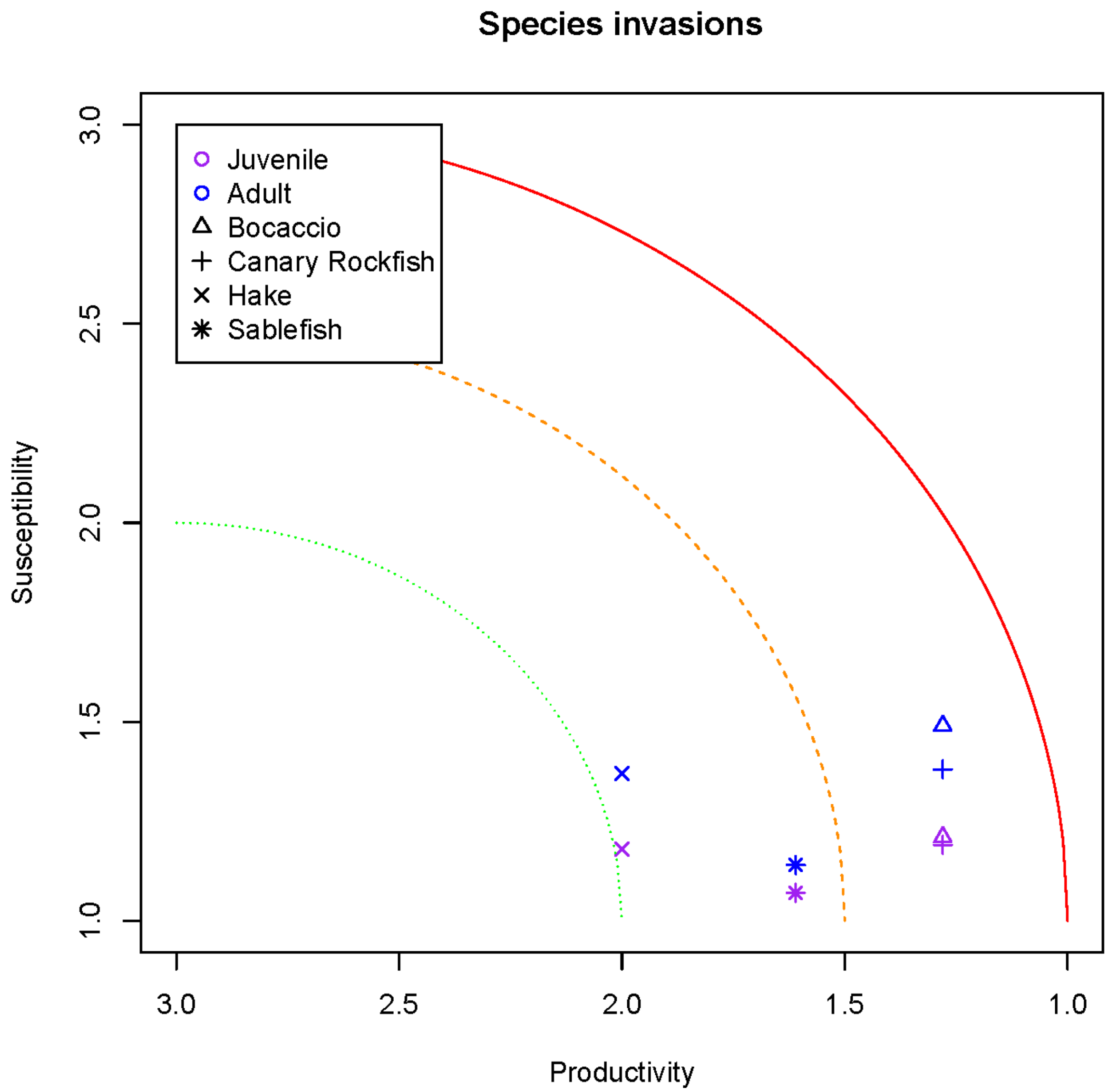

Figure GFR15. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to species invasions as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

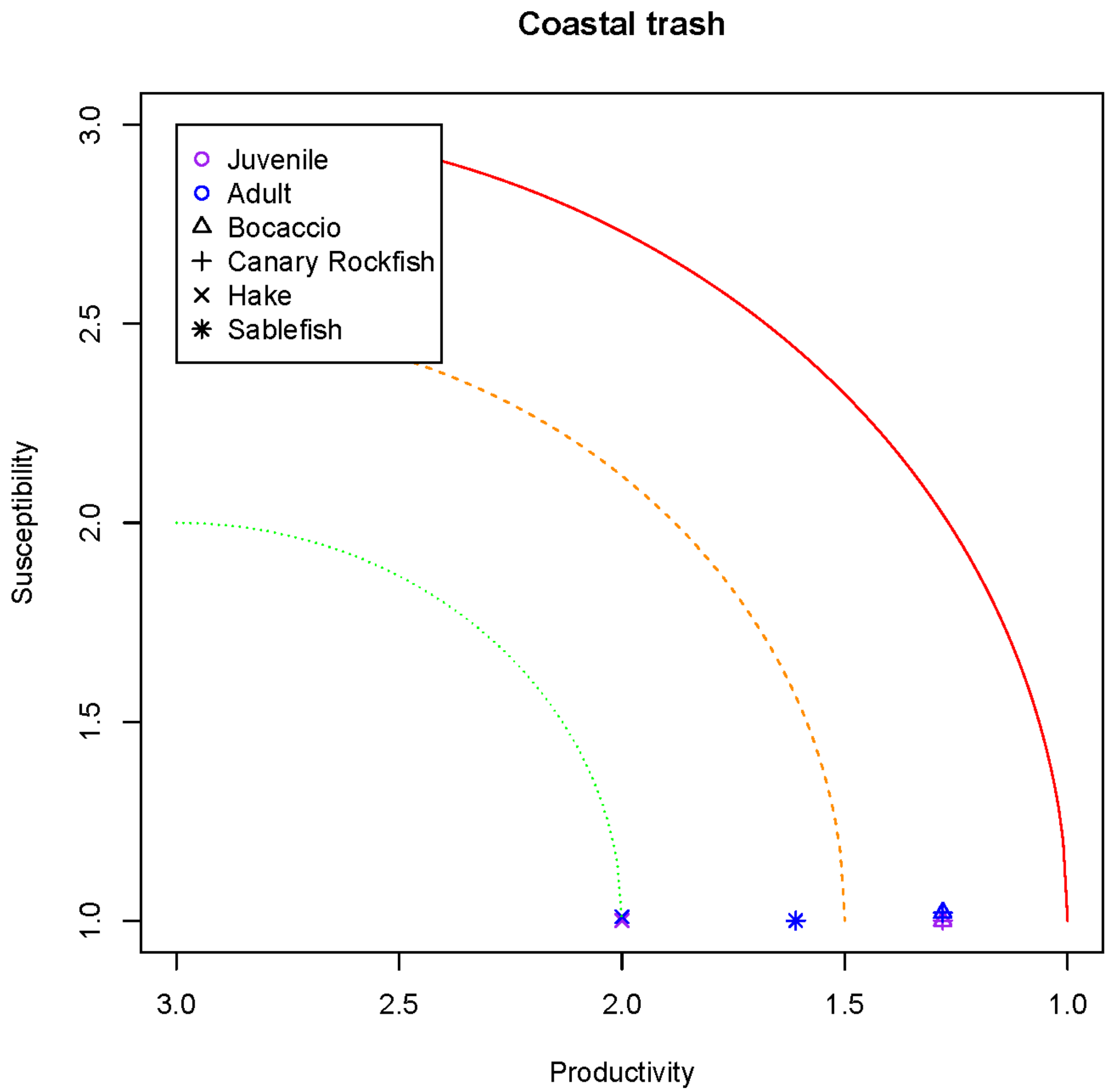

Figure GFR16. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to trash as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

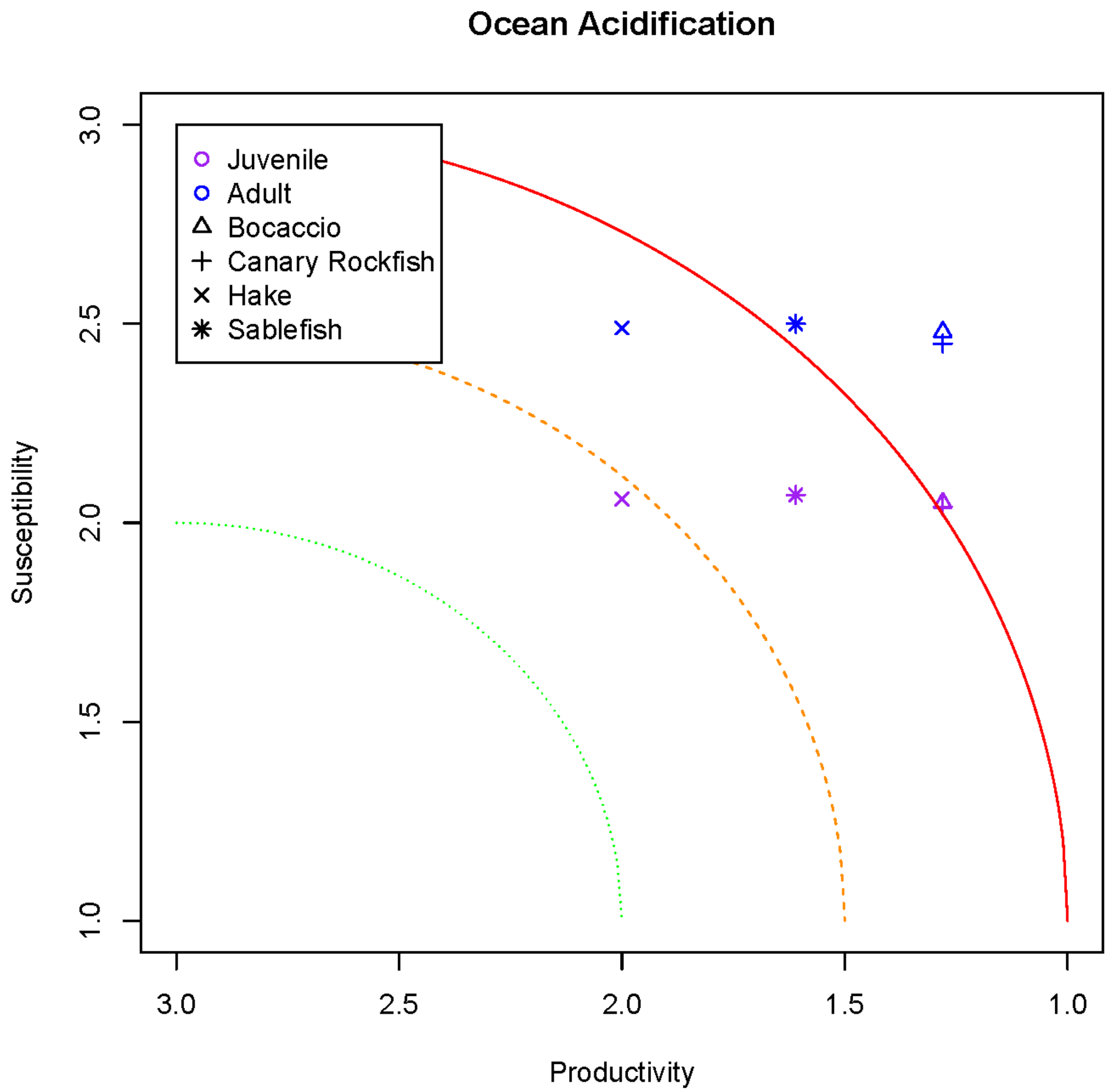

Figure GFR17. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to ocean acidification as a threat The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

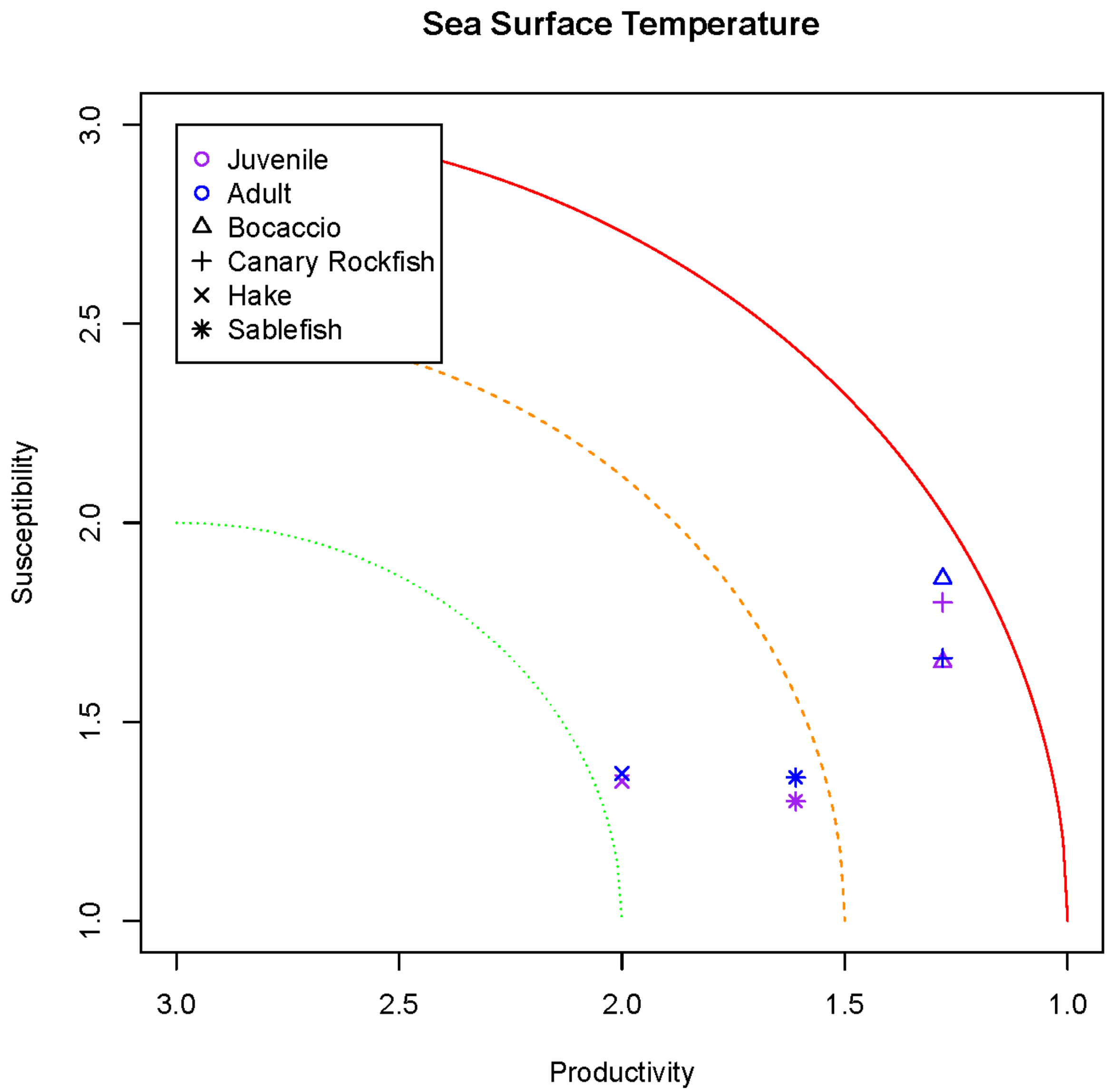

Figure GFR18. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to sea surface temperature as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

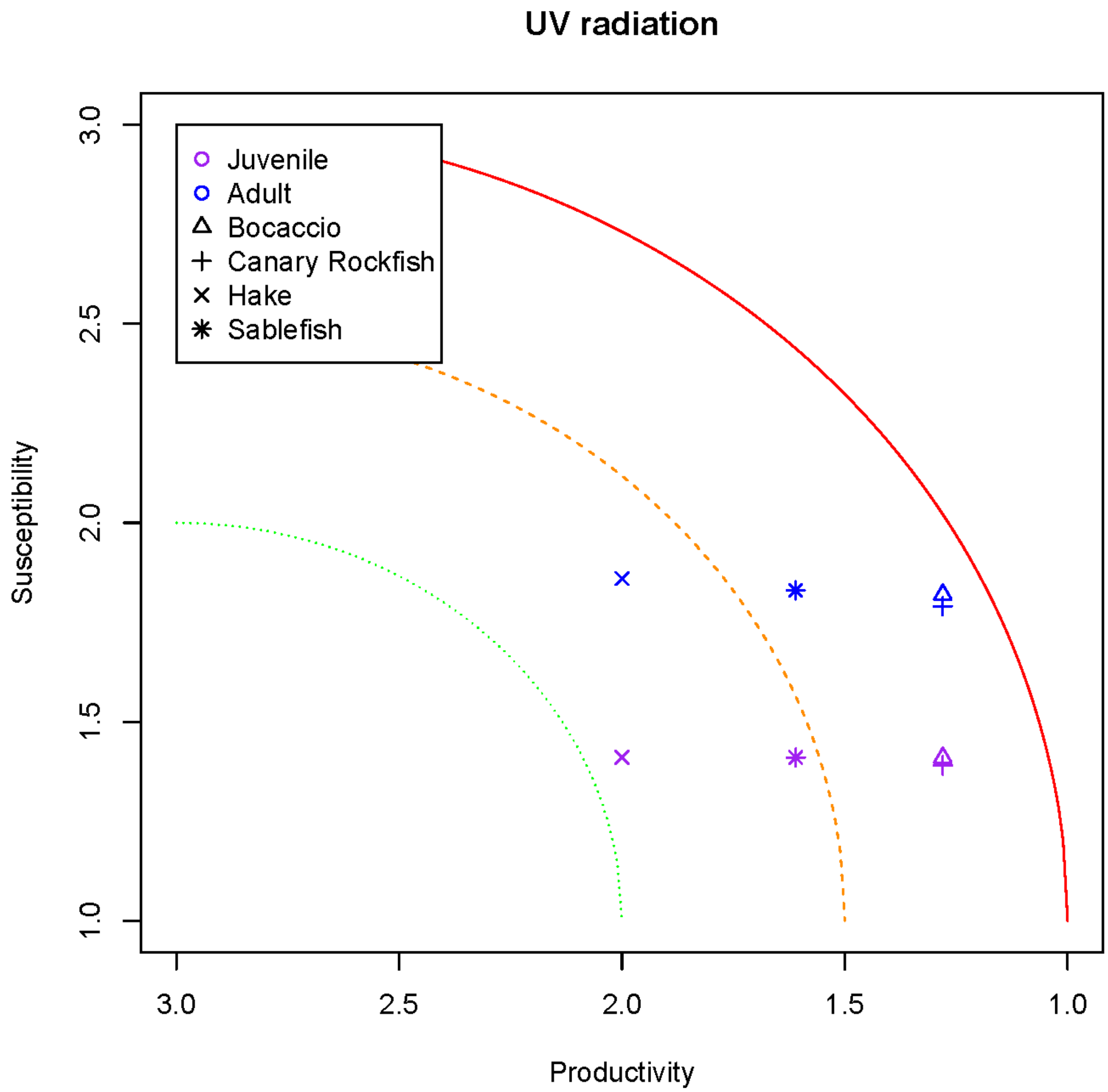

Figure GFR19. Productivity-susceptibility analysis (PSA) plot for the 8 species/stages relative to ultraviolet radiation as a threat. The susceptibility axis represents a relative score among species and stages but not among threats, though values near one indicate little to no impact in all cases. Where the adult and juvenile Susceptibility scores are identical, the symbols are on top of each other and only the adult values are visible.

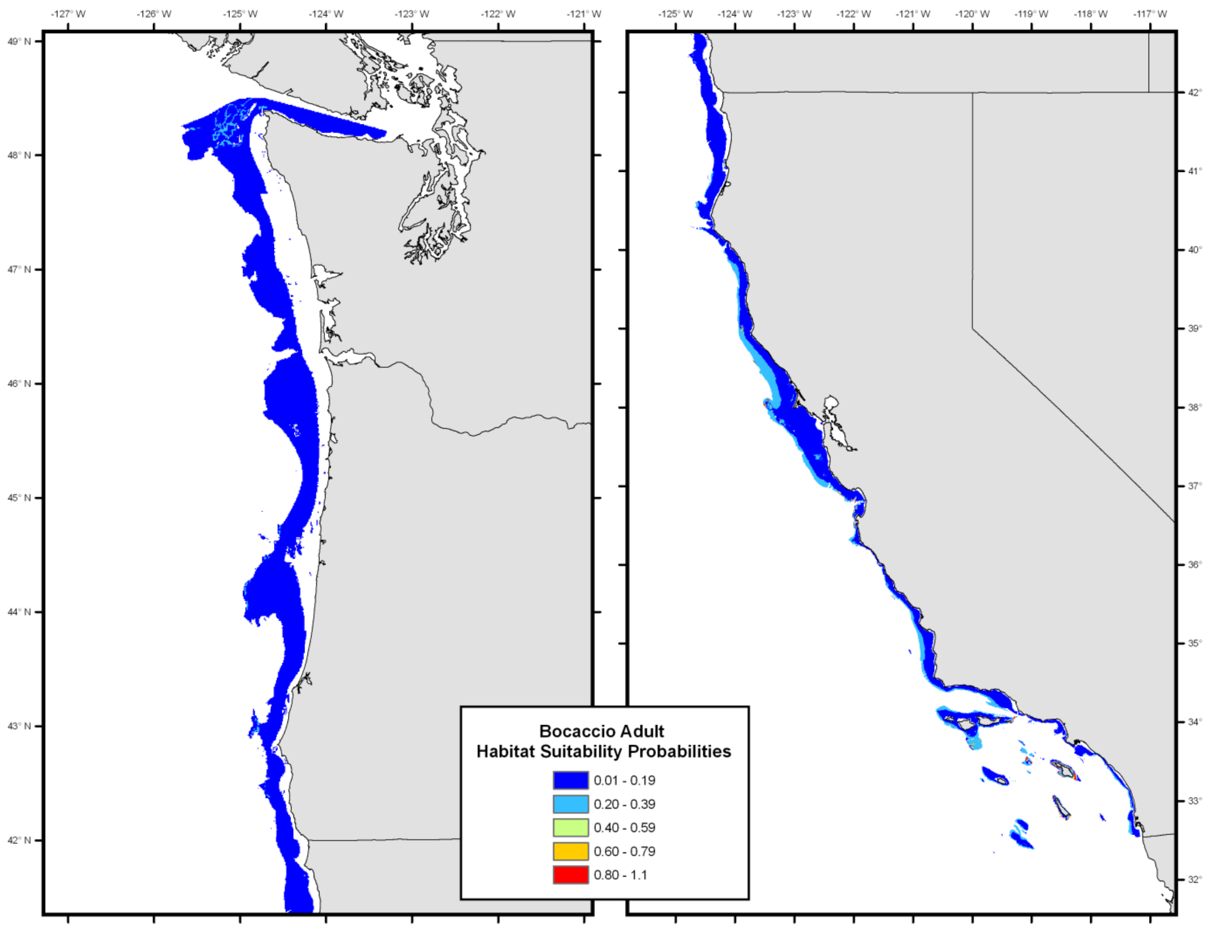

Figure GFR20. Habitat Suitability Probabilities for bocaccio *Sebastes paucispinis* adult. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

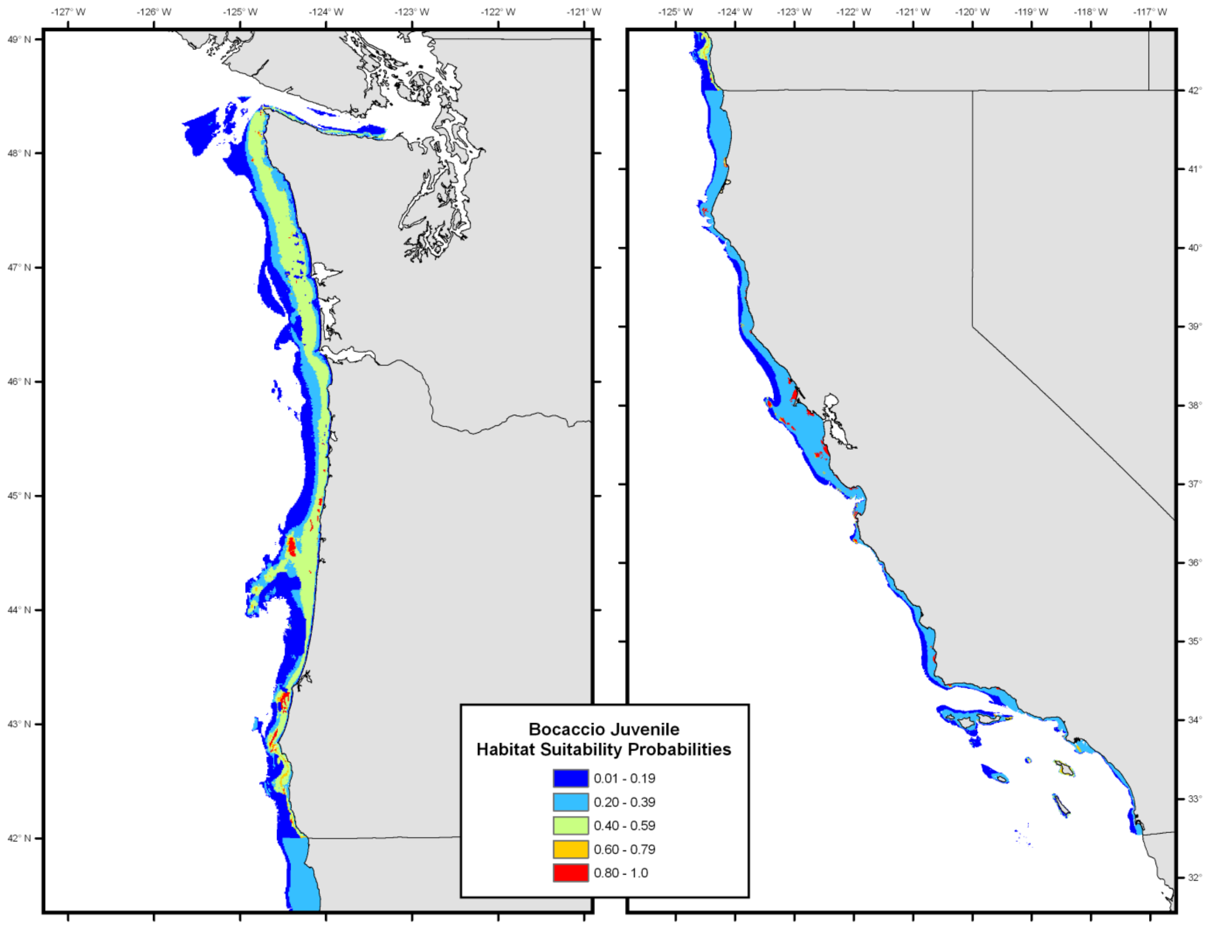

Figure GFR21. Habitat Suitability Probabilities for bocaccio *Sebastes paucispinis* juvenile. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

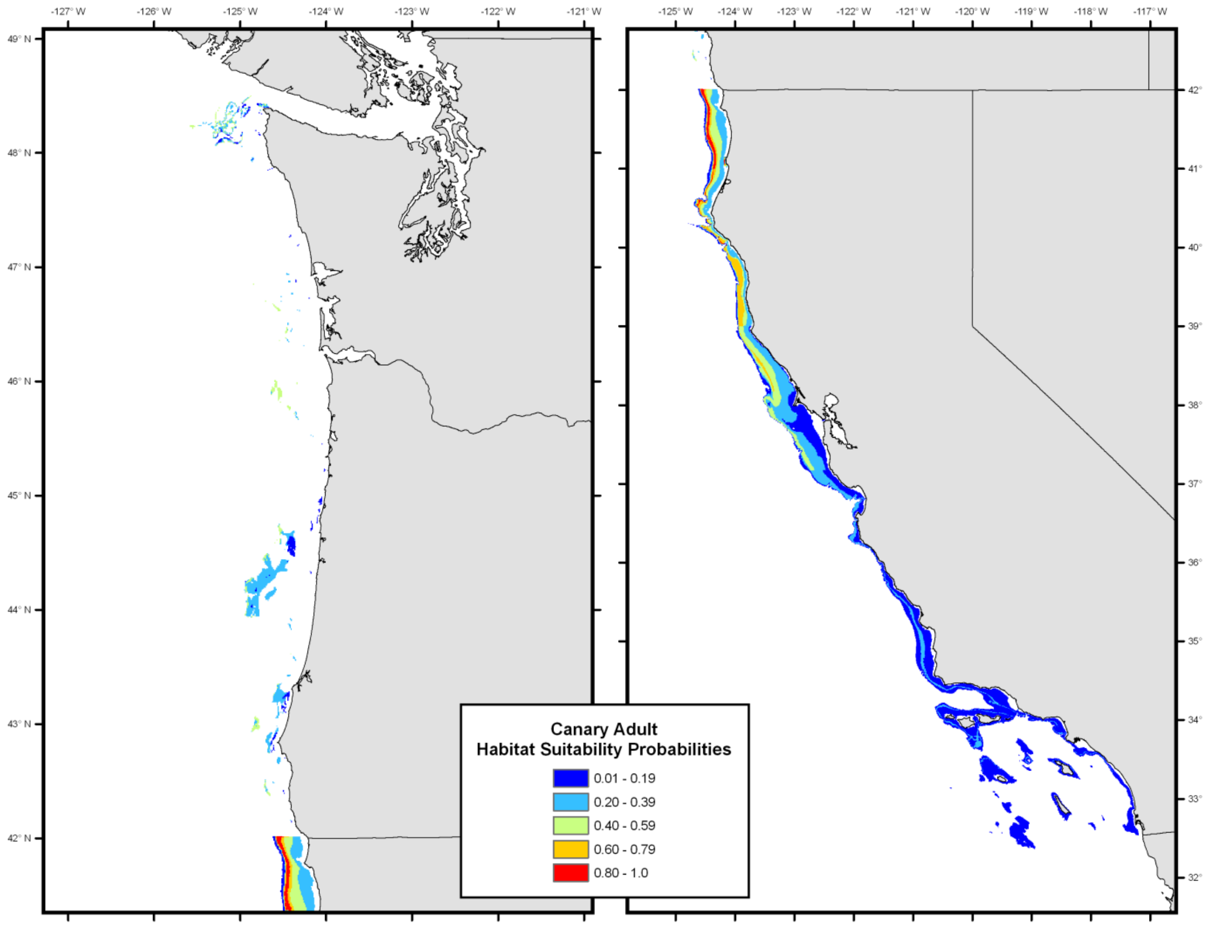

Figure GFR22. Habitat Suitability Probabilities for canary *Sebastes pinniger* adult. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

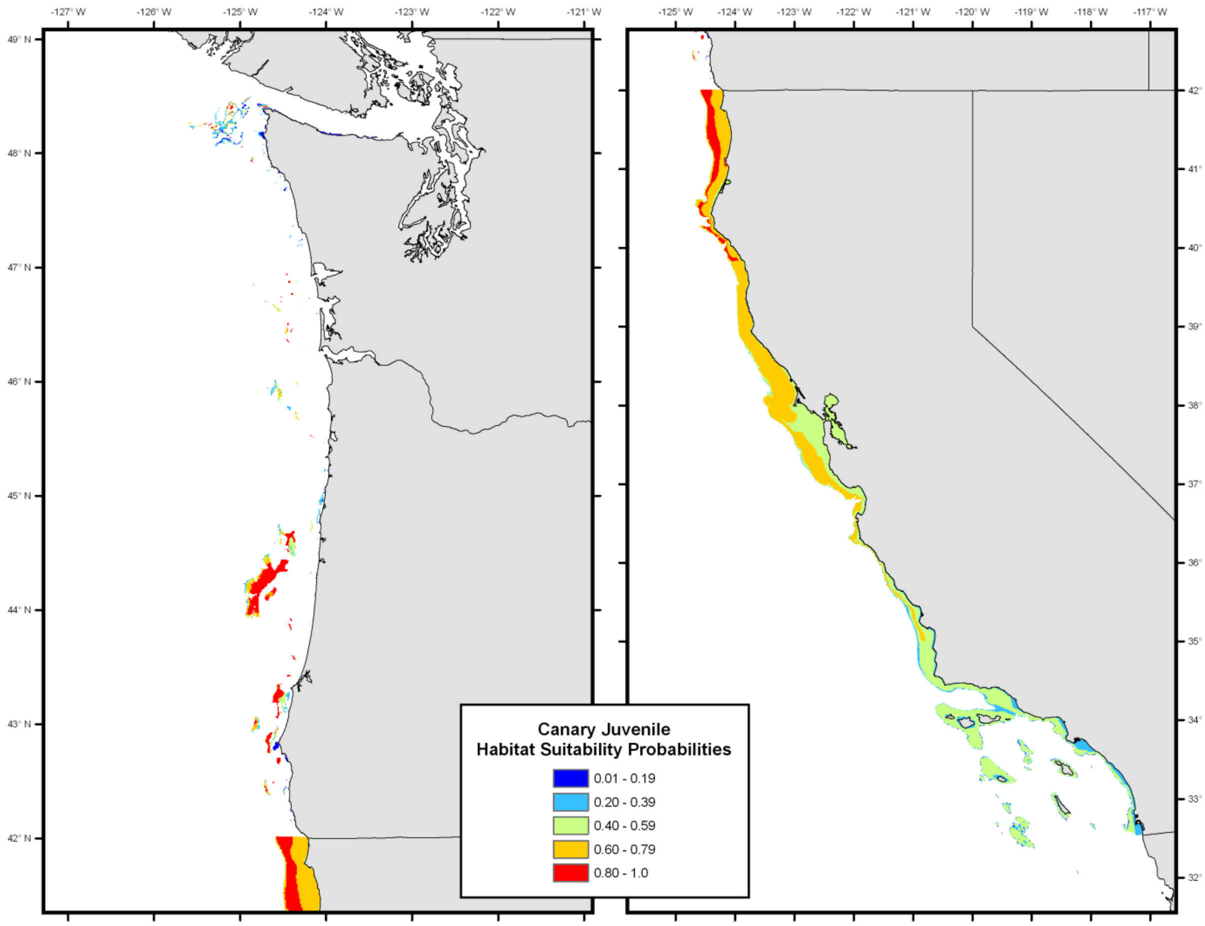

Figure GFR23. Habitat Suitability Probabilities for canary *Sebastes pinniger* juvenile. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

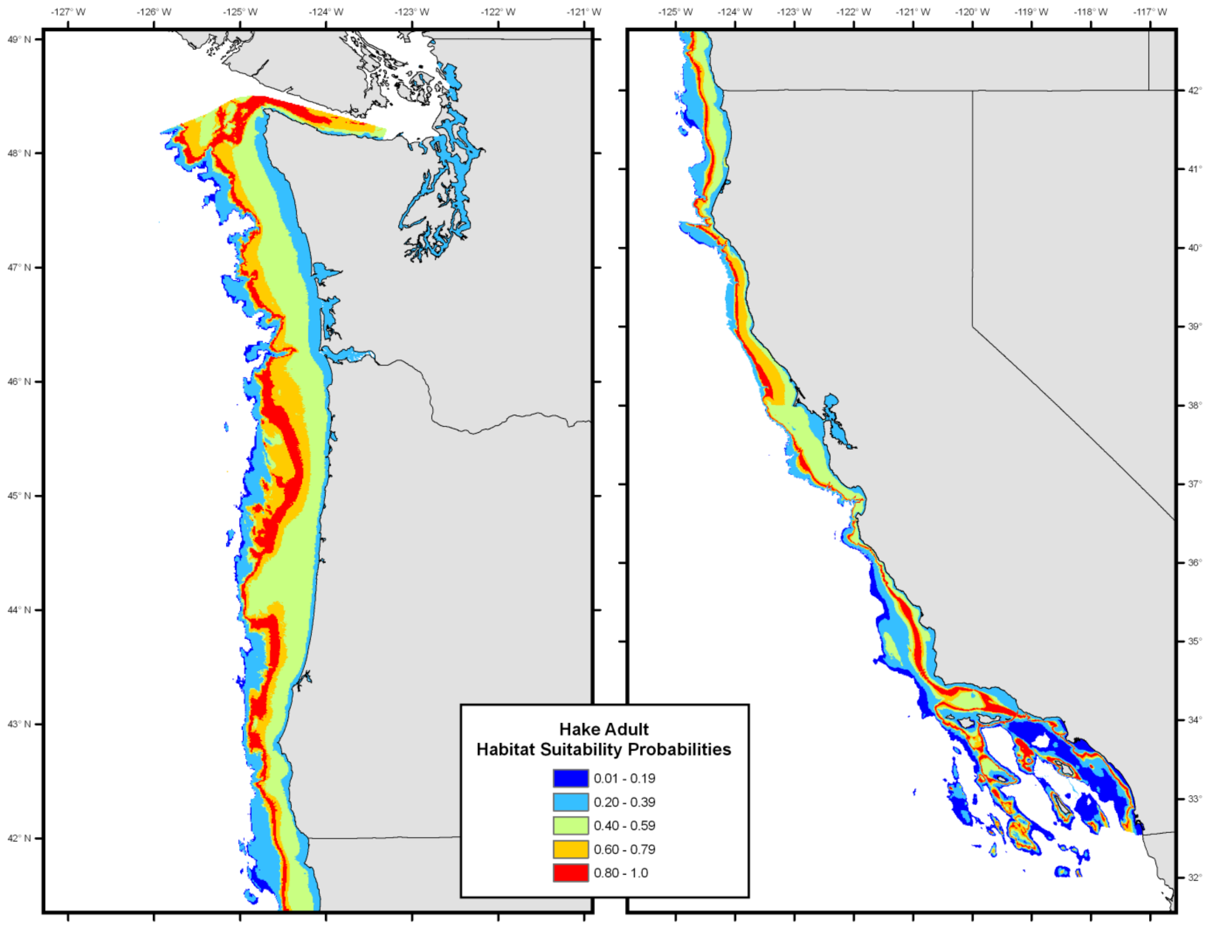

Figure GFR24. Habitat Suitability Probabilities for Pacific hake *Merluccius productus* adult. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

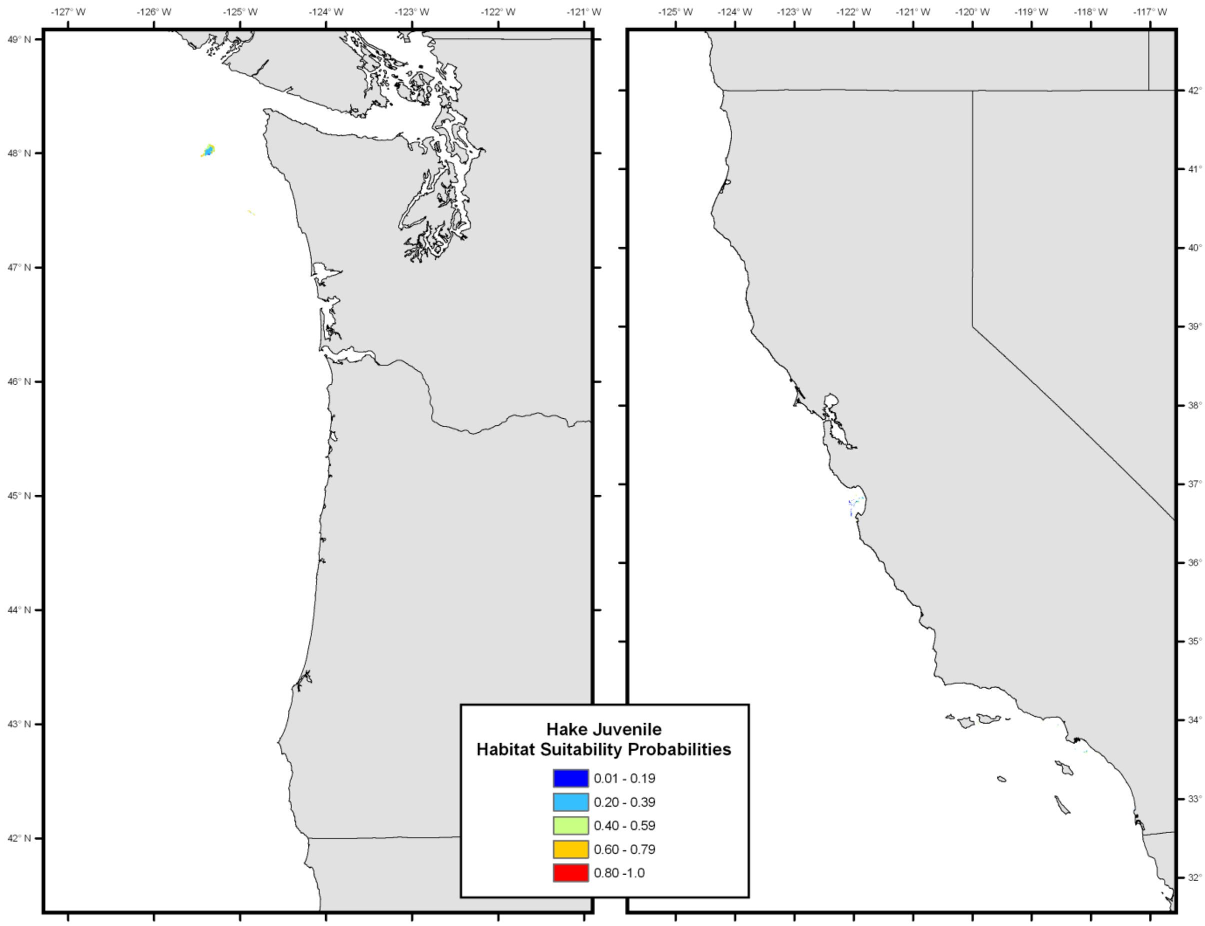

Figure GFR25. Habitat Suitability Probabilities for Pacific hake *Merluccius productus* juvenile. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

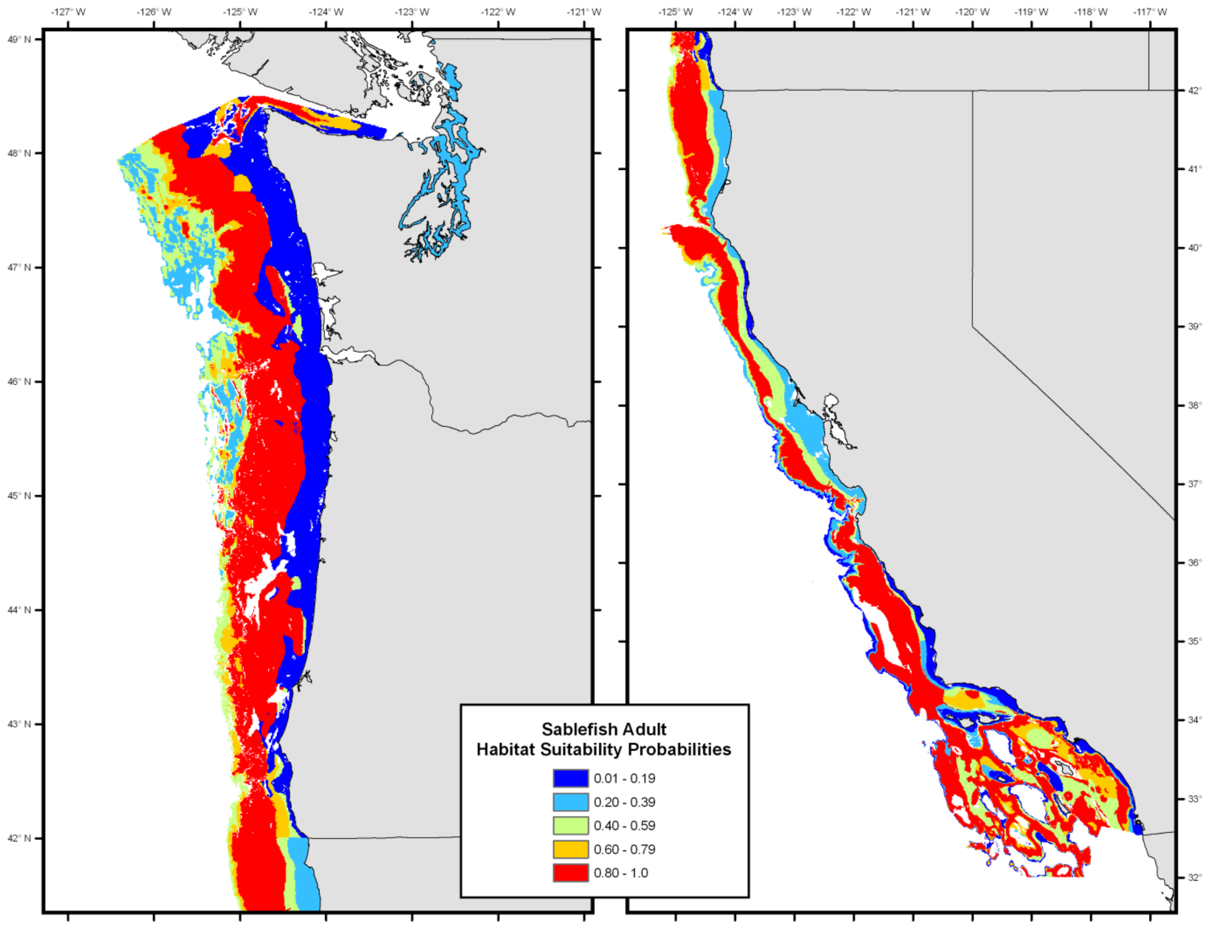

Figure GFR26. Habitat Suitability Probabilities for Sablefish *Anoplopoma fimbria* adult. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

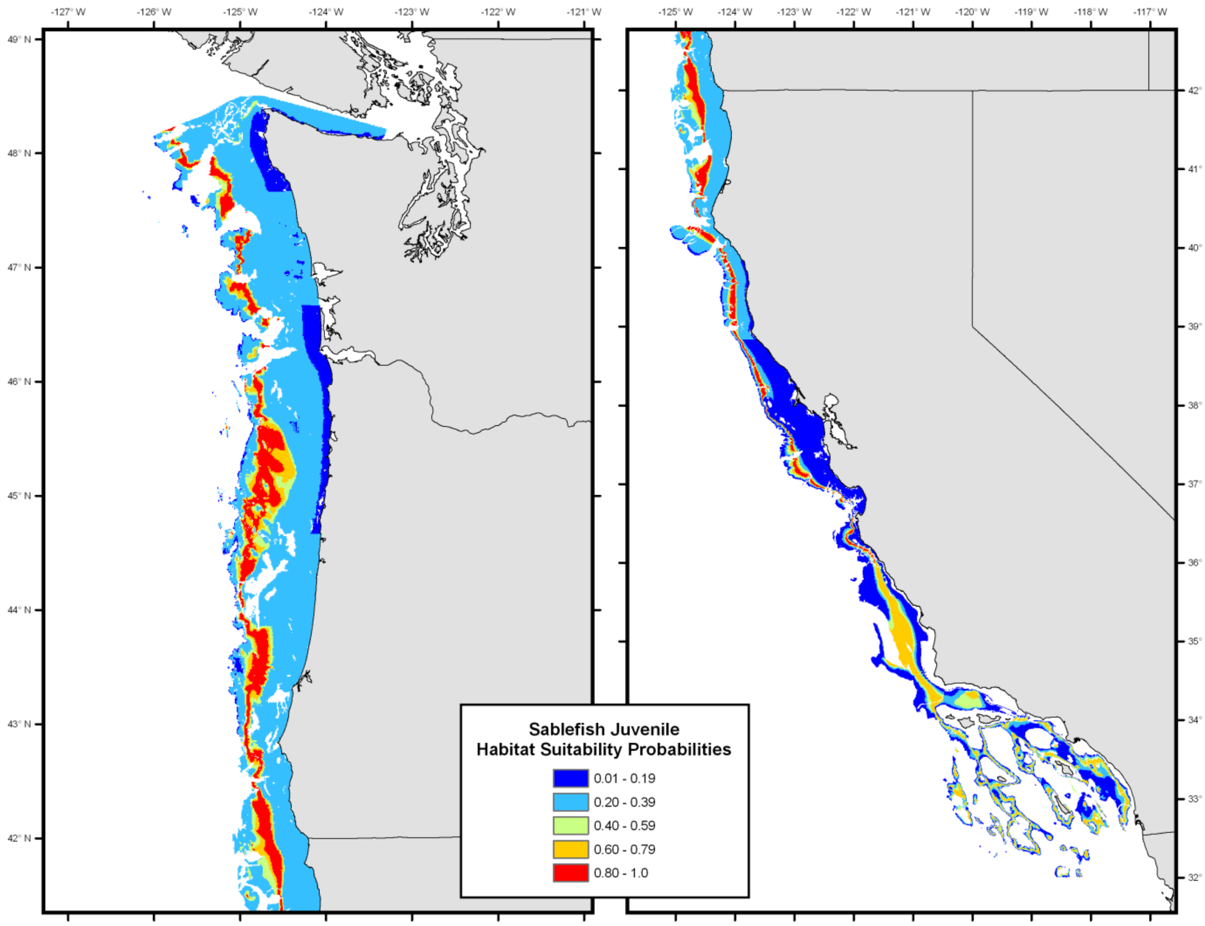

Figure GFR27. Habitat Suitability Probabilities for Sablefish *Anoplopoma fimbria* juvenile. Data from 2005 Essential Fish Habitat Final Environmental Impact Statement.

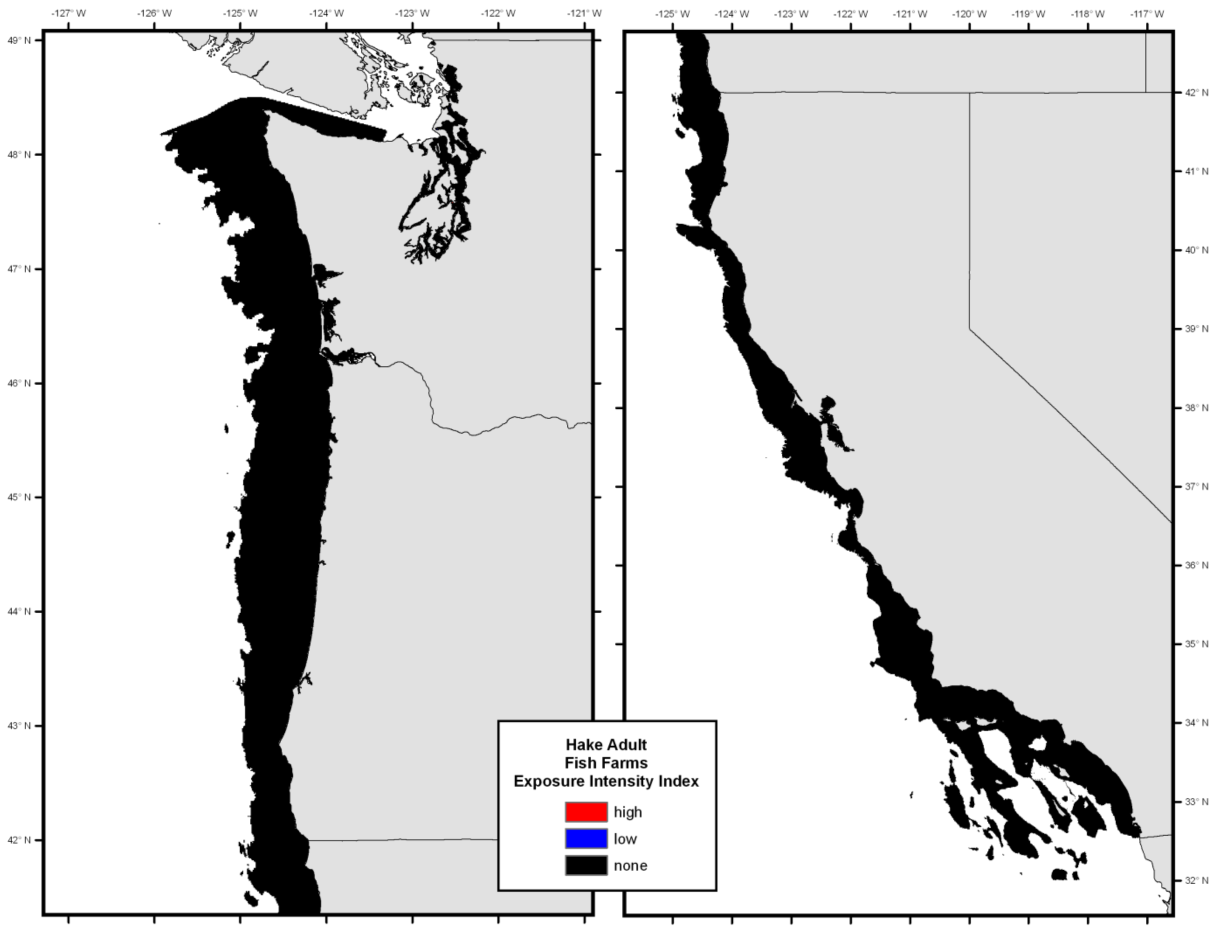

Figure GFR28. Exposure intensity index of aquaculture for Pacific hake *Merluccius productus* adult. High = upper bicile, and low = lower bicile.

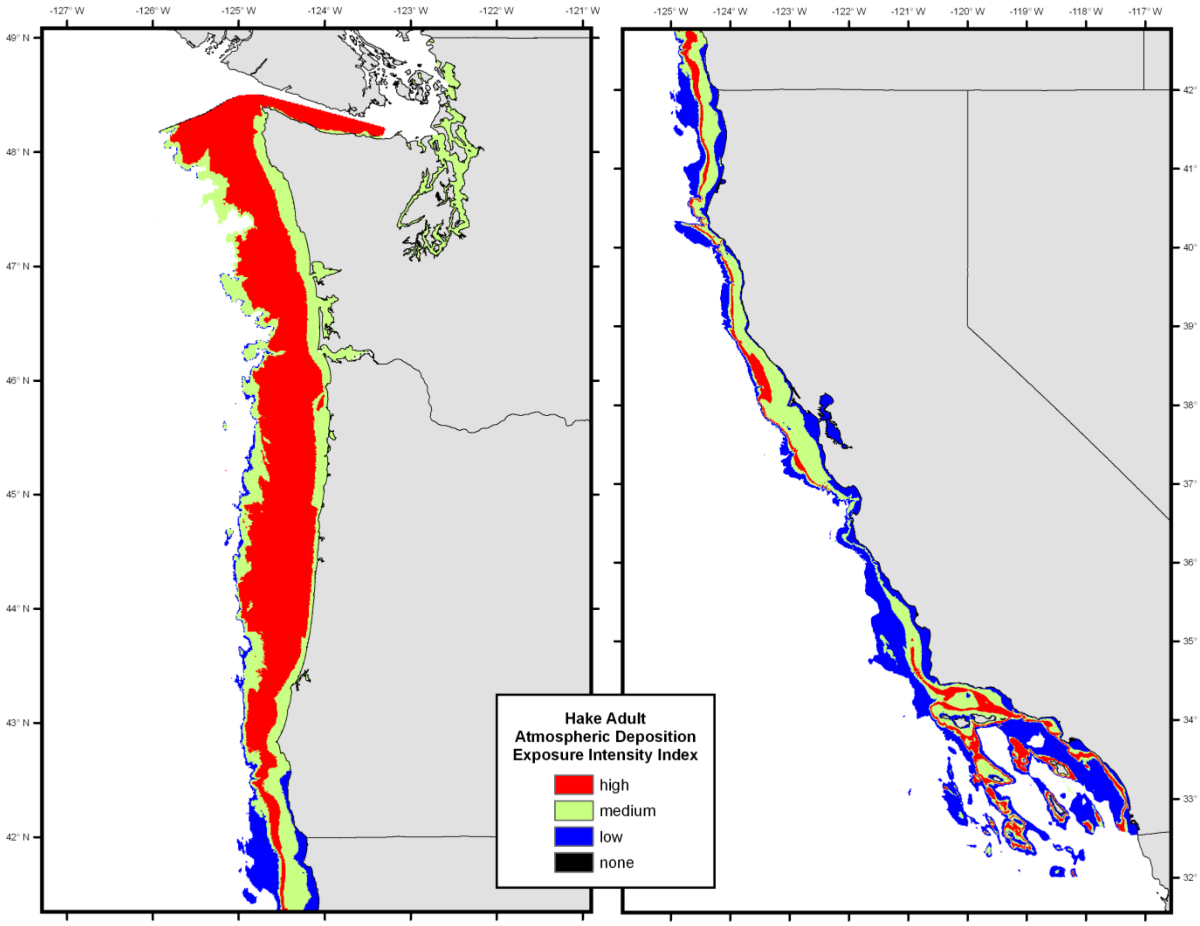

Figure GFR29. Exposure intensity index of atmospheric deposition of pollutants for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

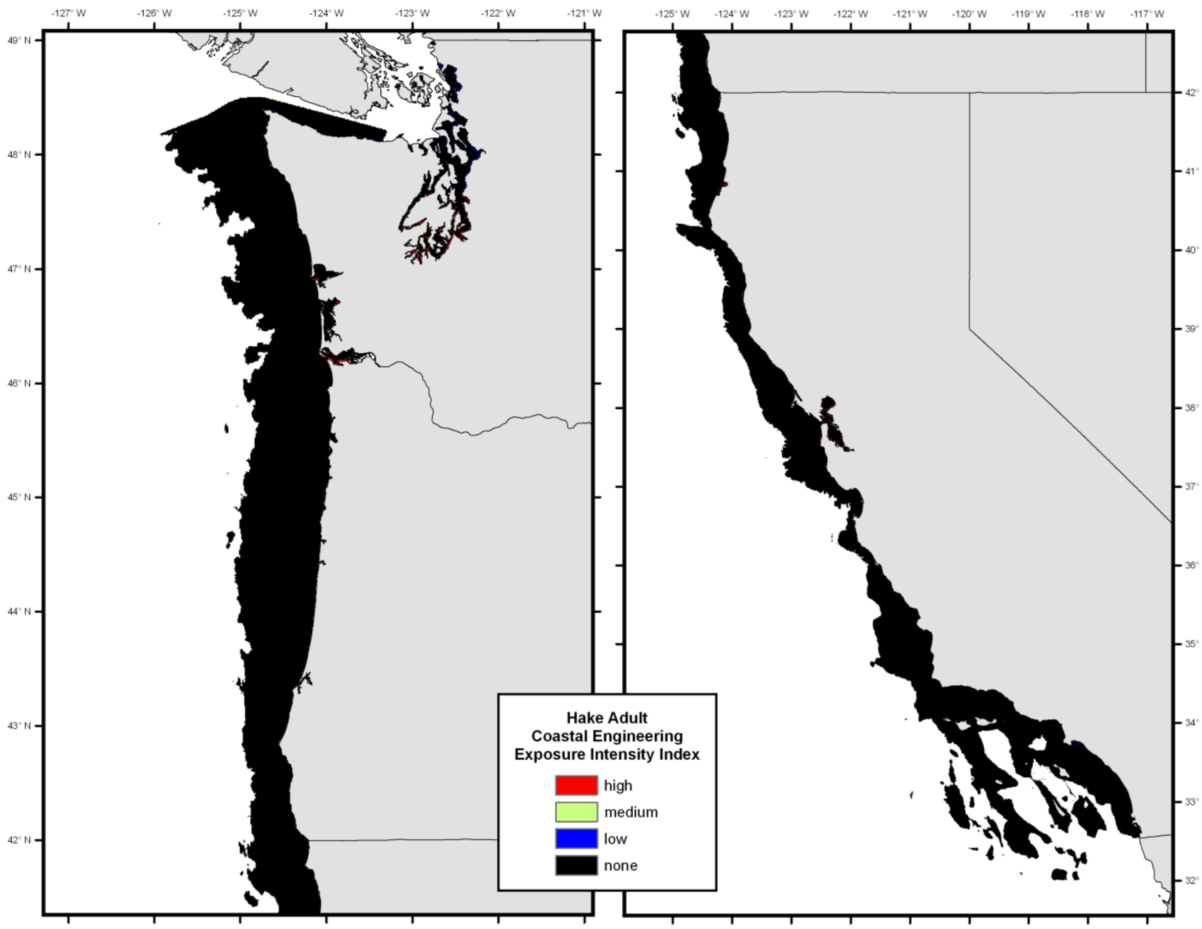

Figure GFR30. Exposure intensity index of coastal engineering for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

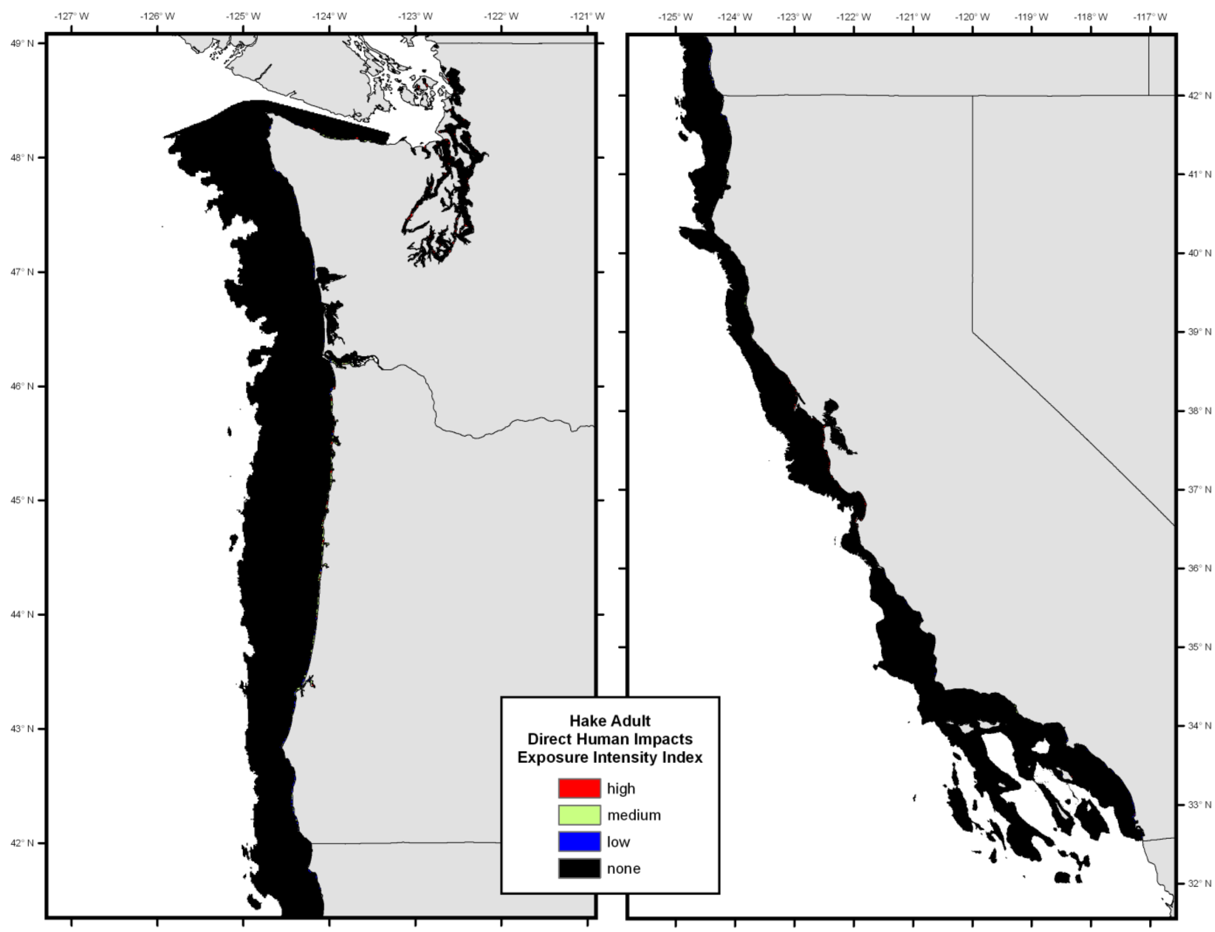

Figure GFR31. Exposure intensity index of direct human impacts (beach trampling) for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

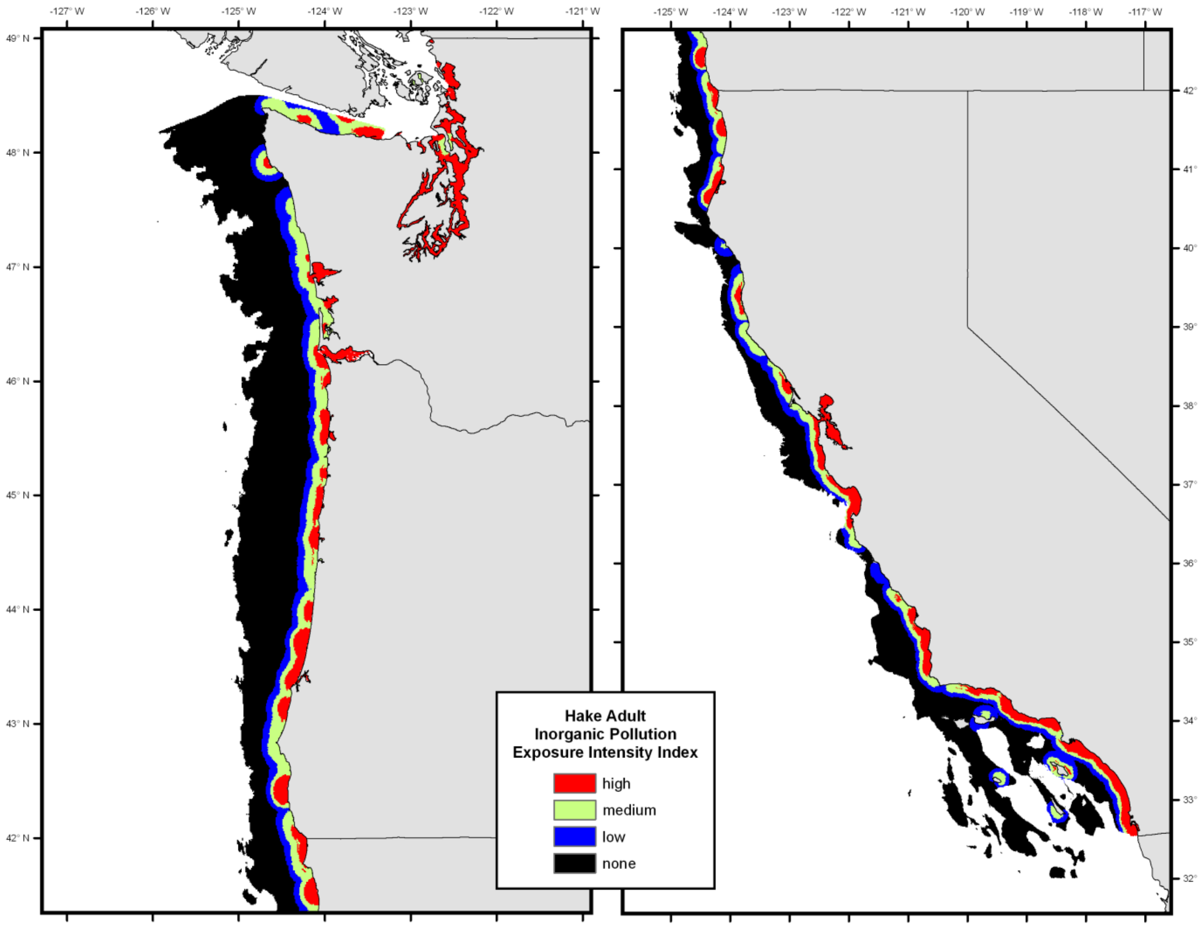

Figure GFR32. Exposure intensity index of inorganic pollution for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

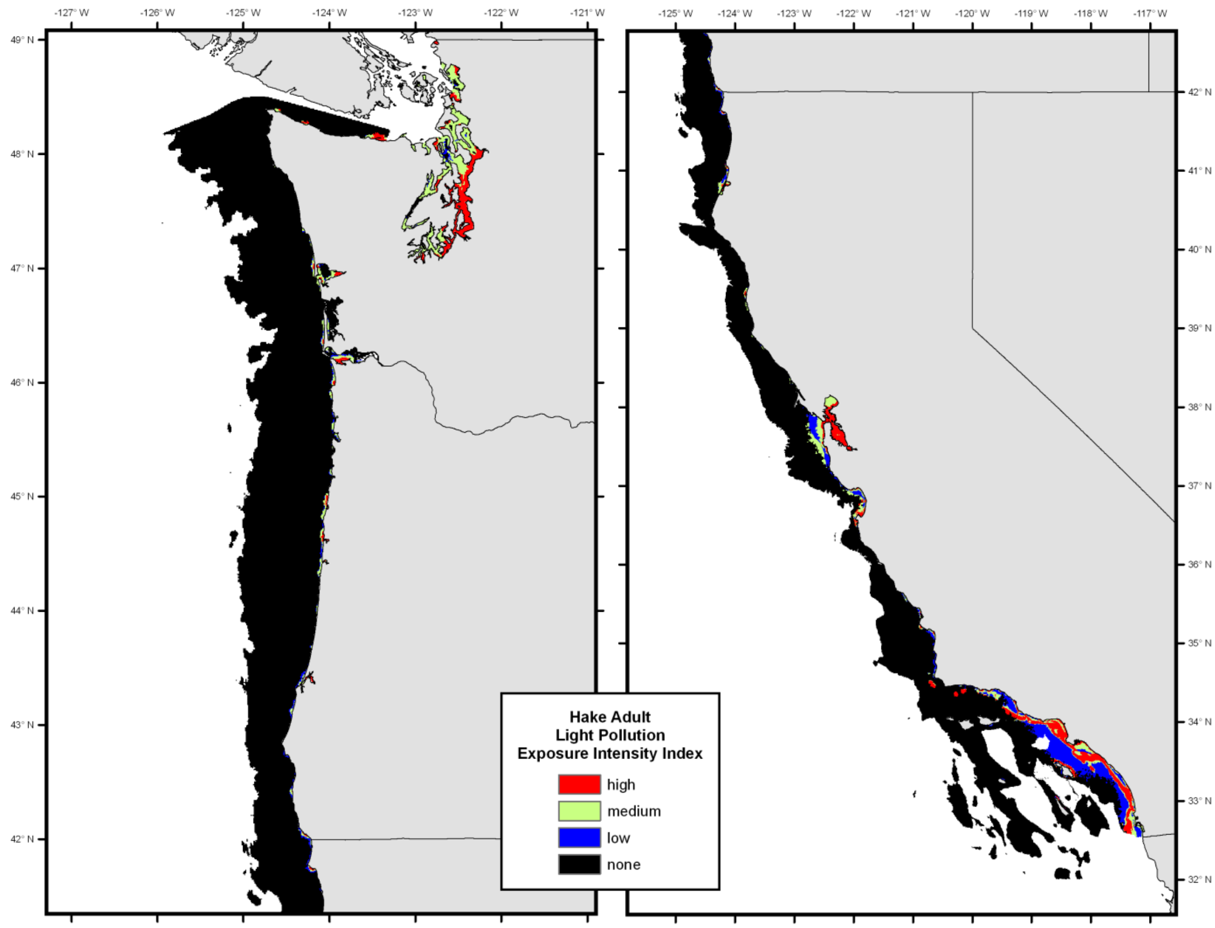

Figure GFR33. Exposure intensity index of light pollution for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

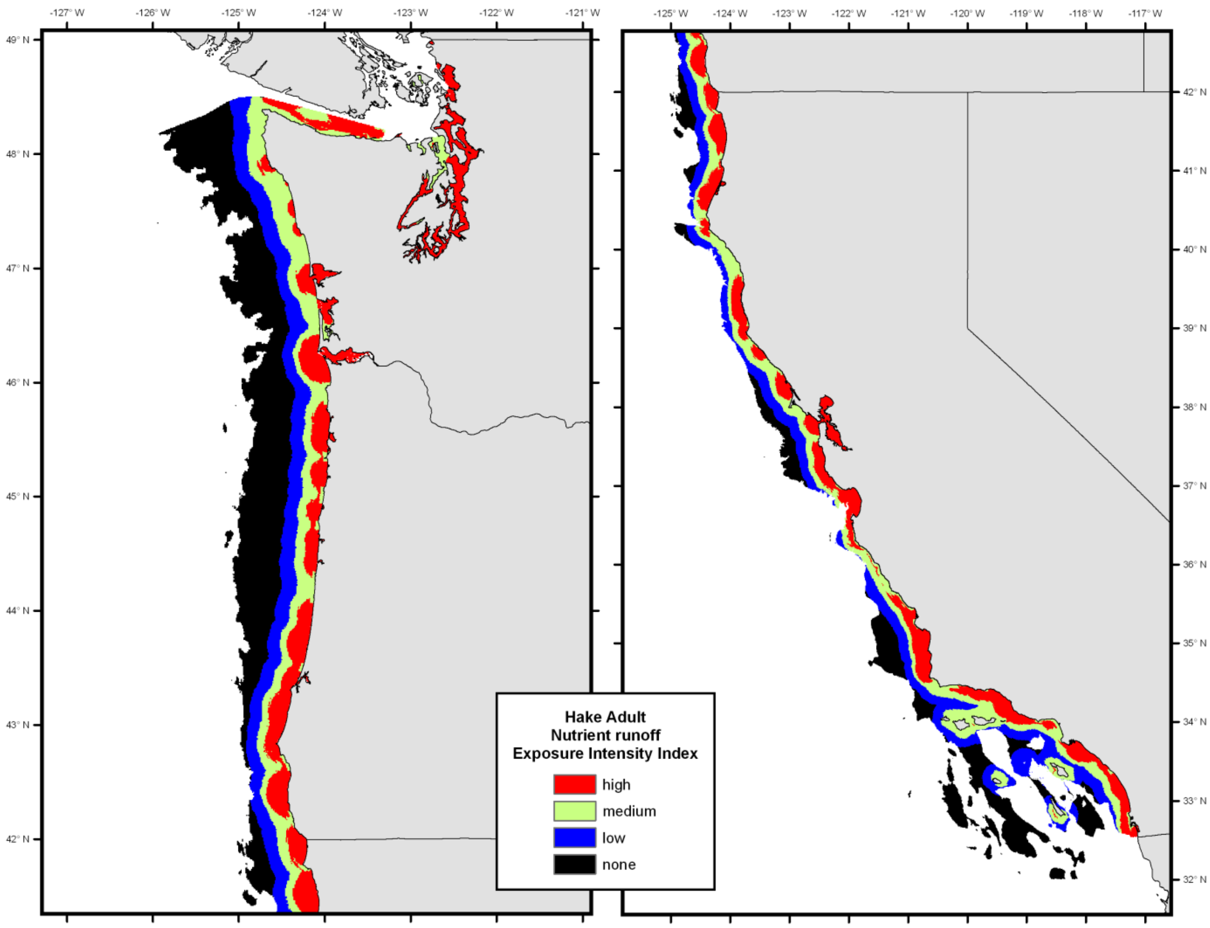

Figure GFR34. Exposure intensity index of nutrient runoff for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

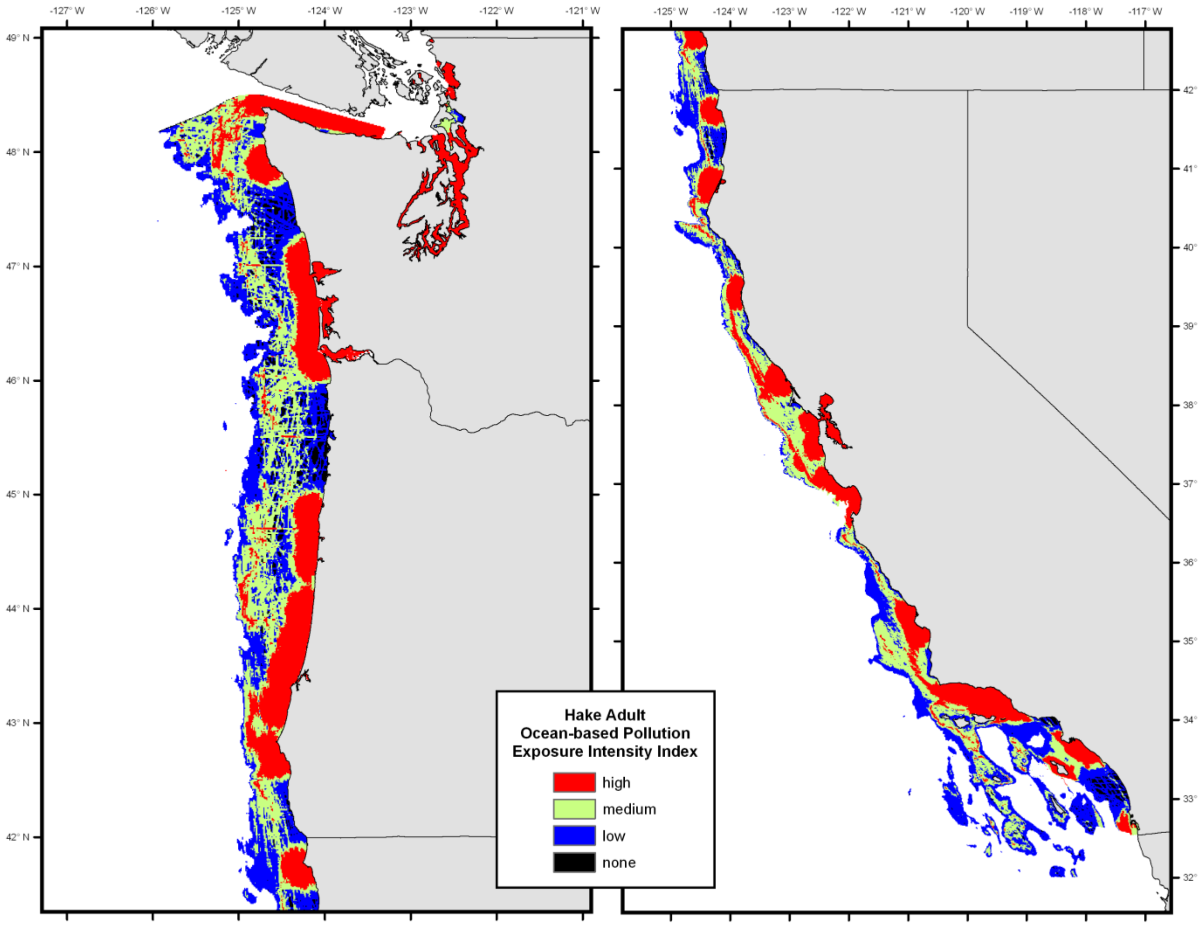

Figure GFR35. Exposure intensity index of ocean-based pollution for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

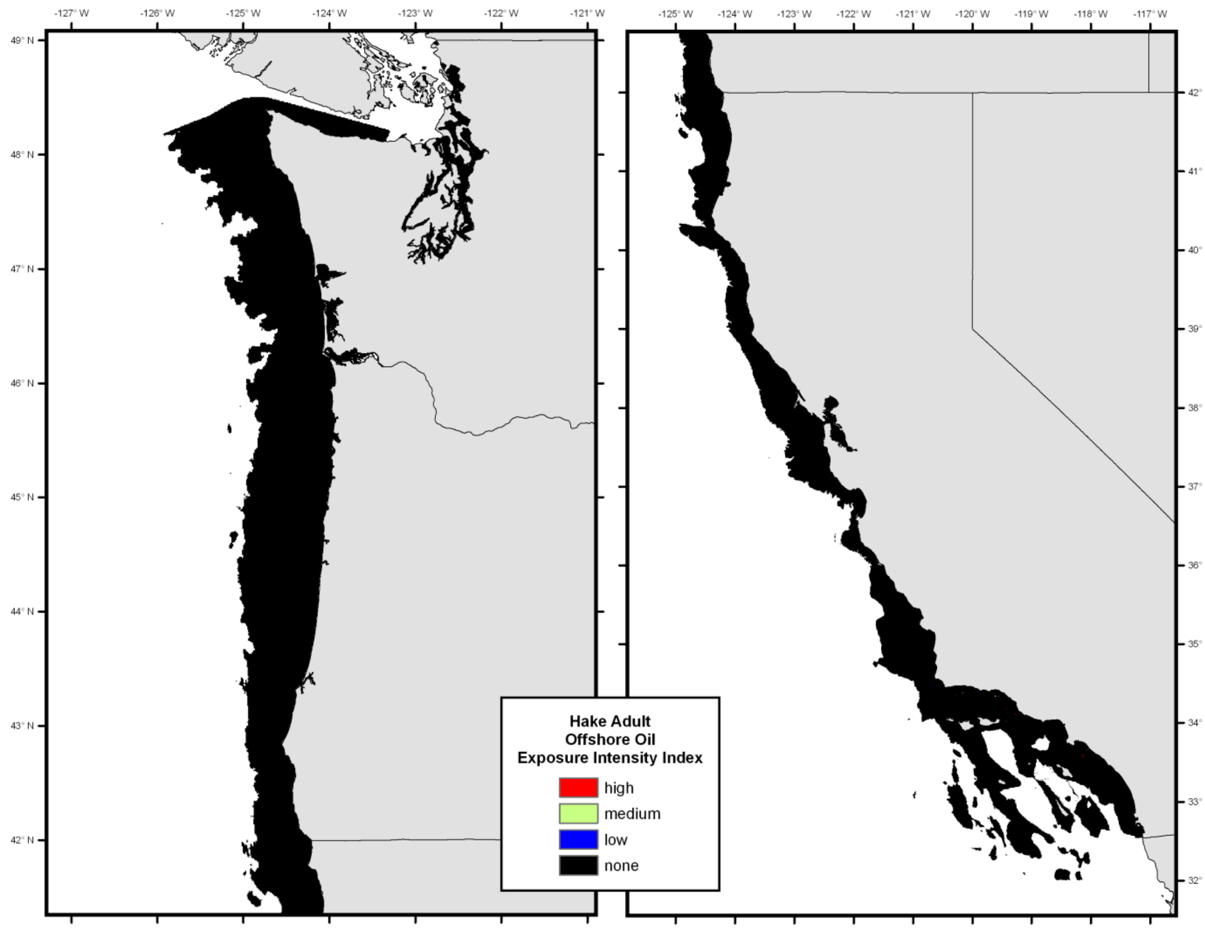

Figure GFR36. Exposure intensity index of offshore oil activities for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

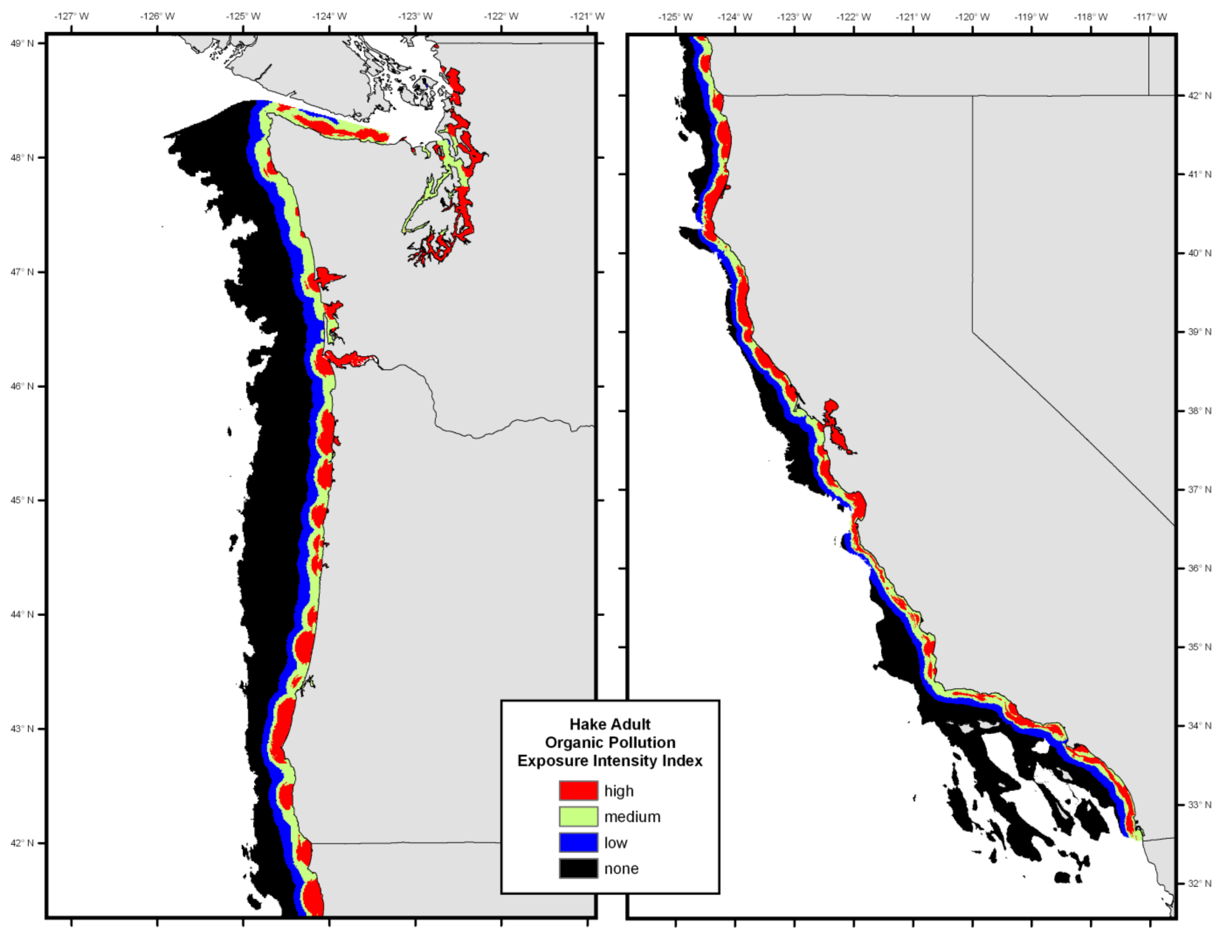

Figure GFR37. Exposure intensity index of organic pollution for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

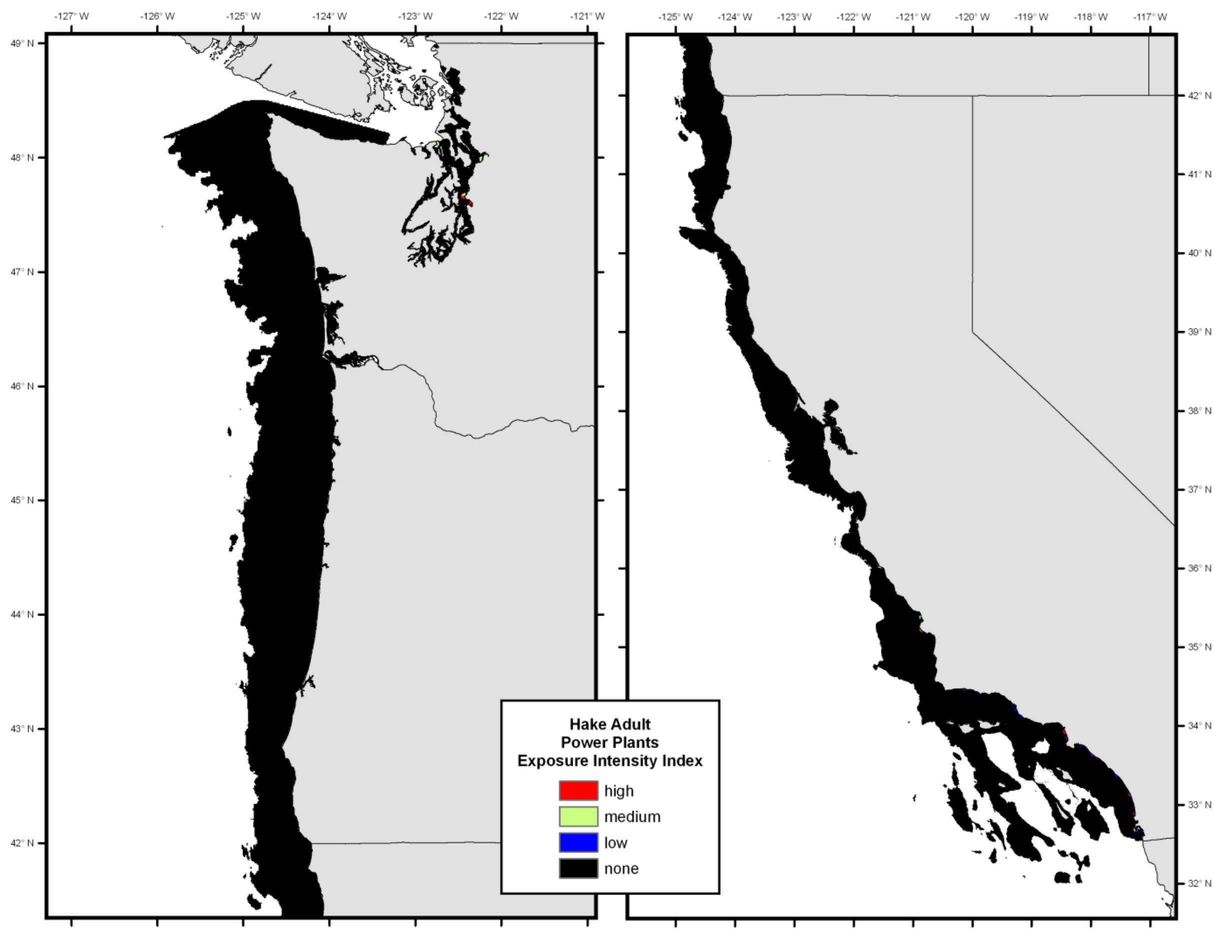

Figure GFR38. Exposure intensity index of coastal seawater exchange activity for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

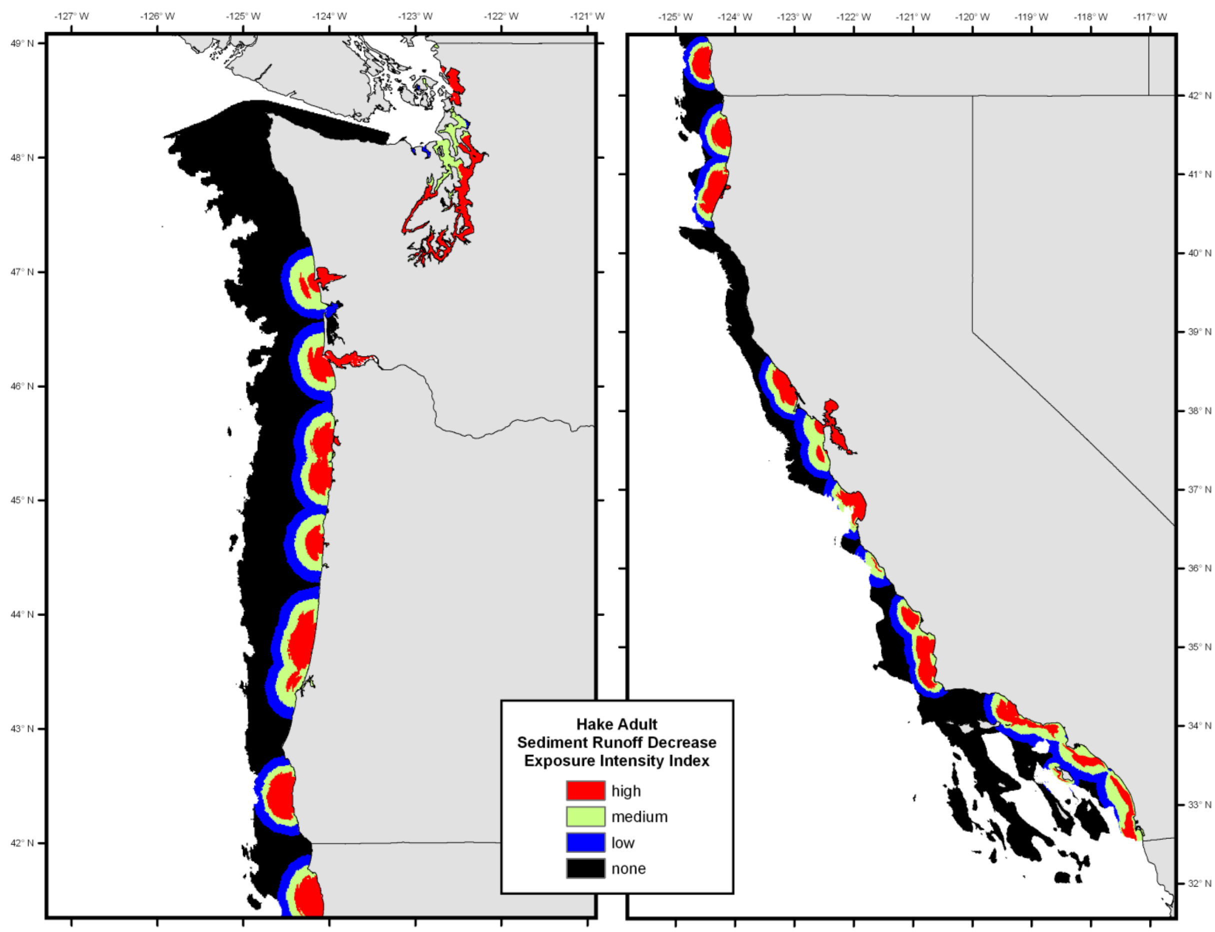

Figure GFR39. Exposure intensity index of sediment runoff decrease for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

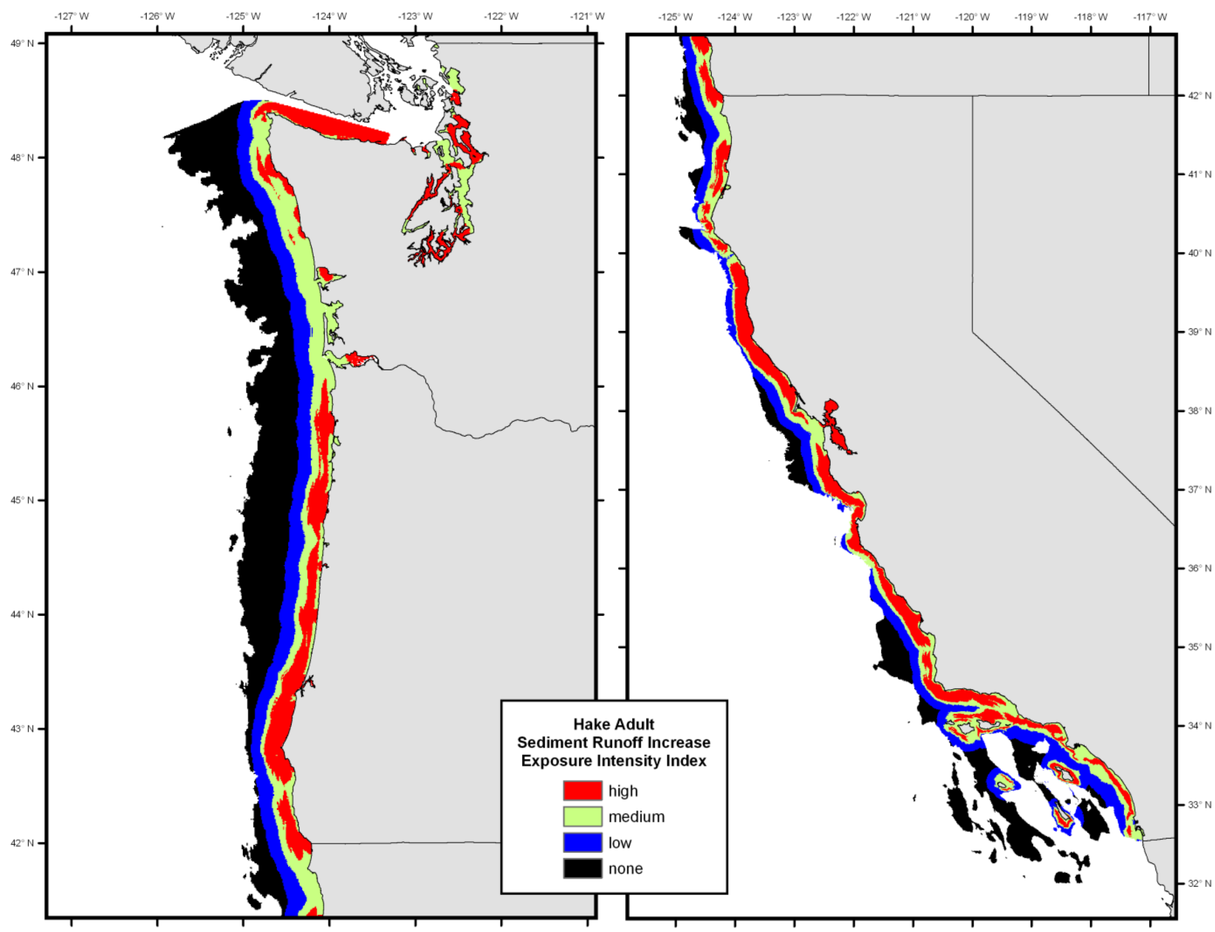

Figure GFR40. Exposure intensity index of sediment runoff increase for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

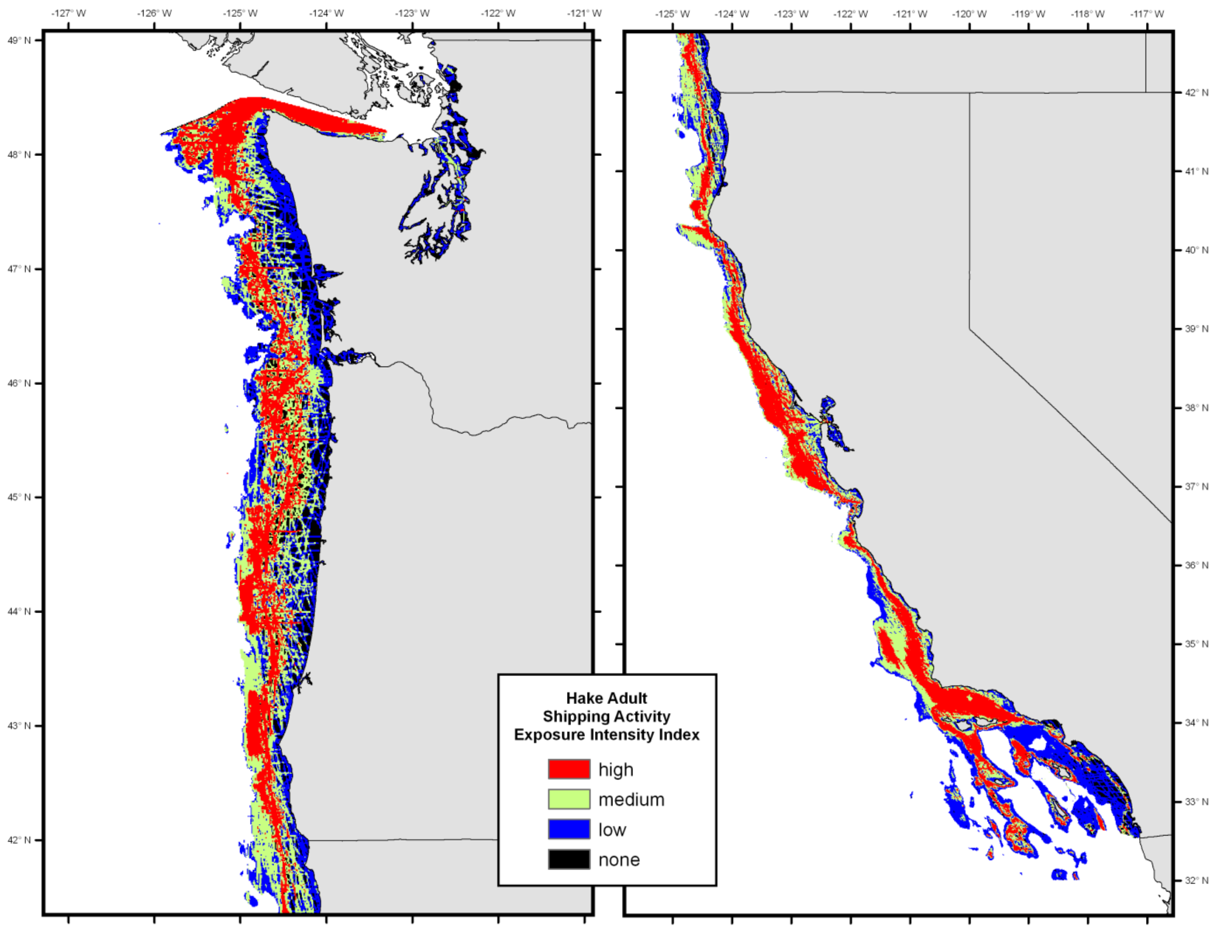

Figure GFR41. Exposure intensity index of shipping activity for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

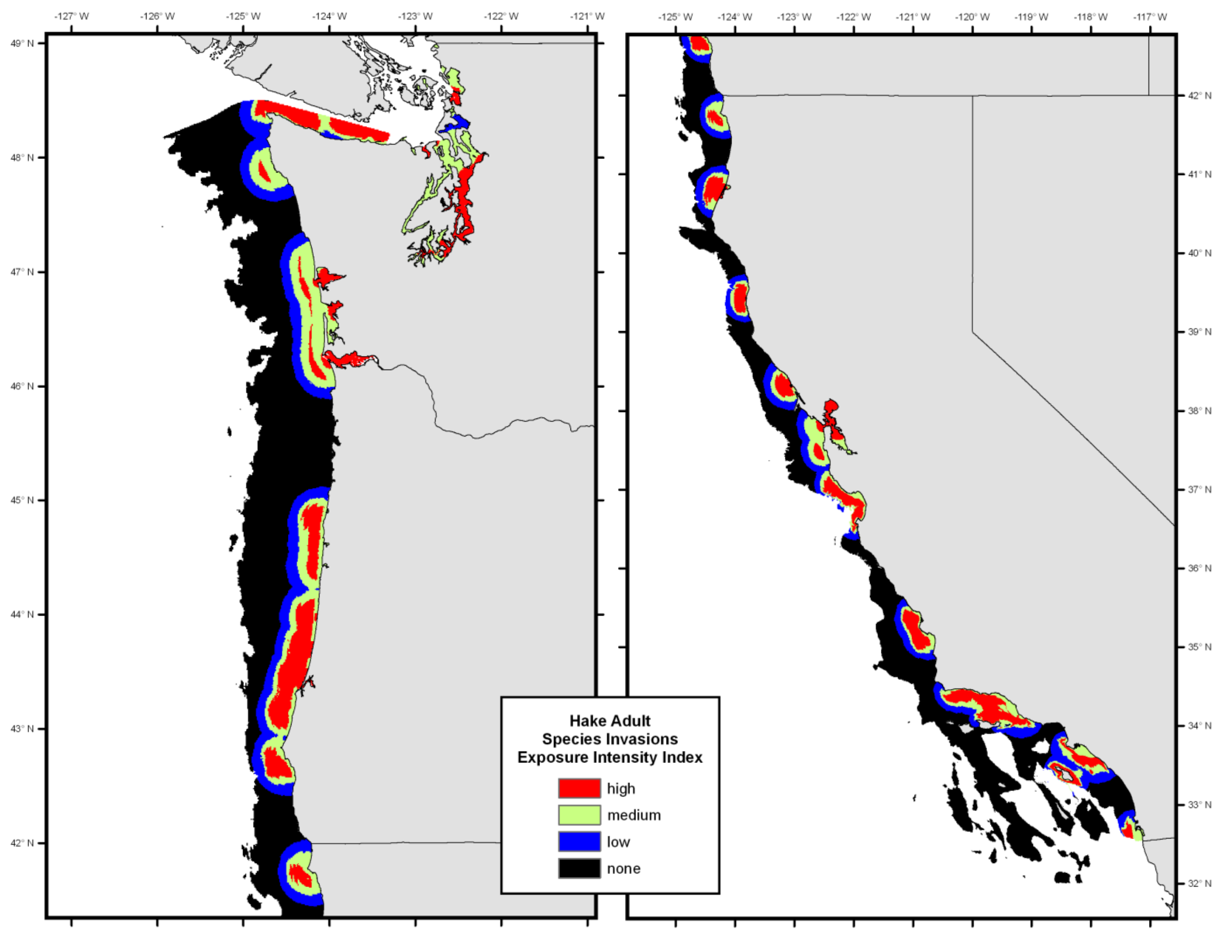

Figure GFR42. Exposure intensity index of species invasions for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

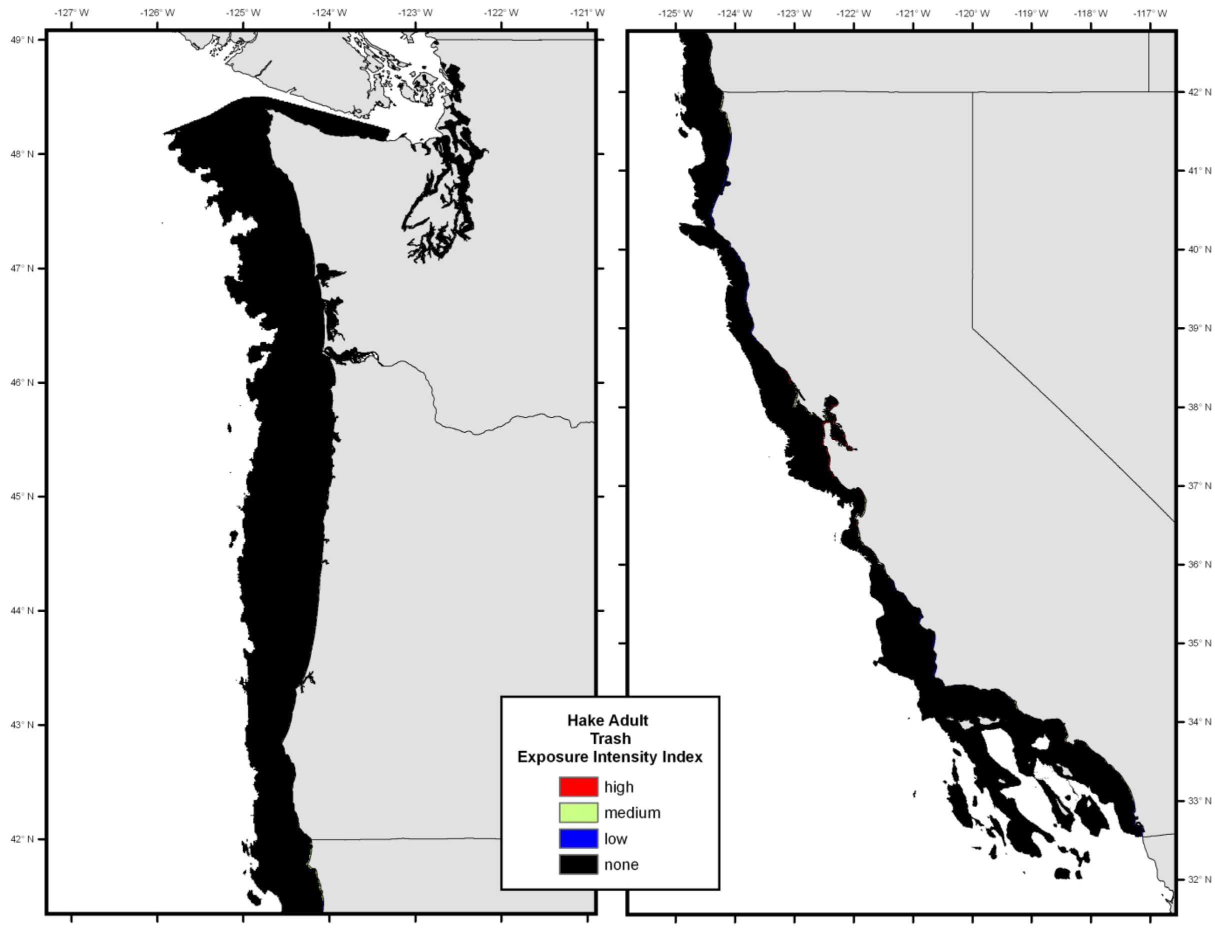

Figure GFR43. Exposure intensity index of coastal trash for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

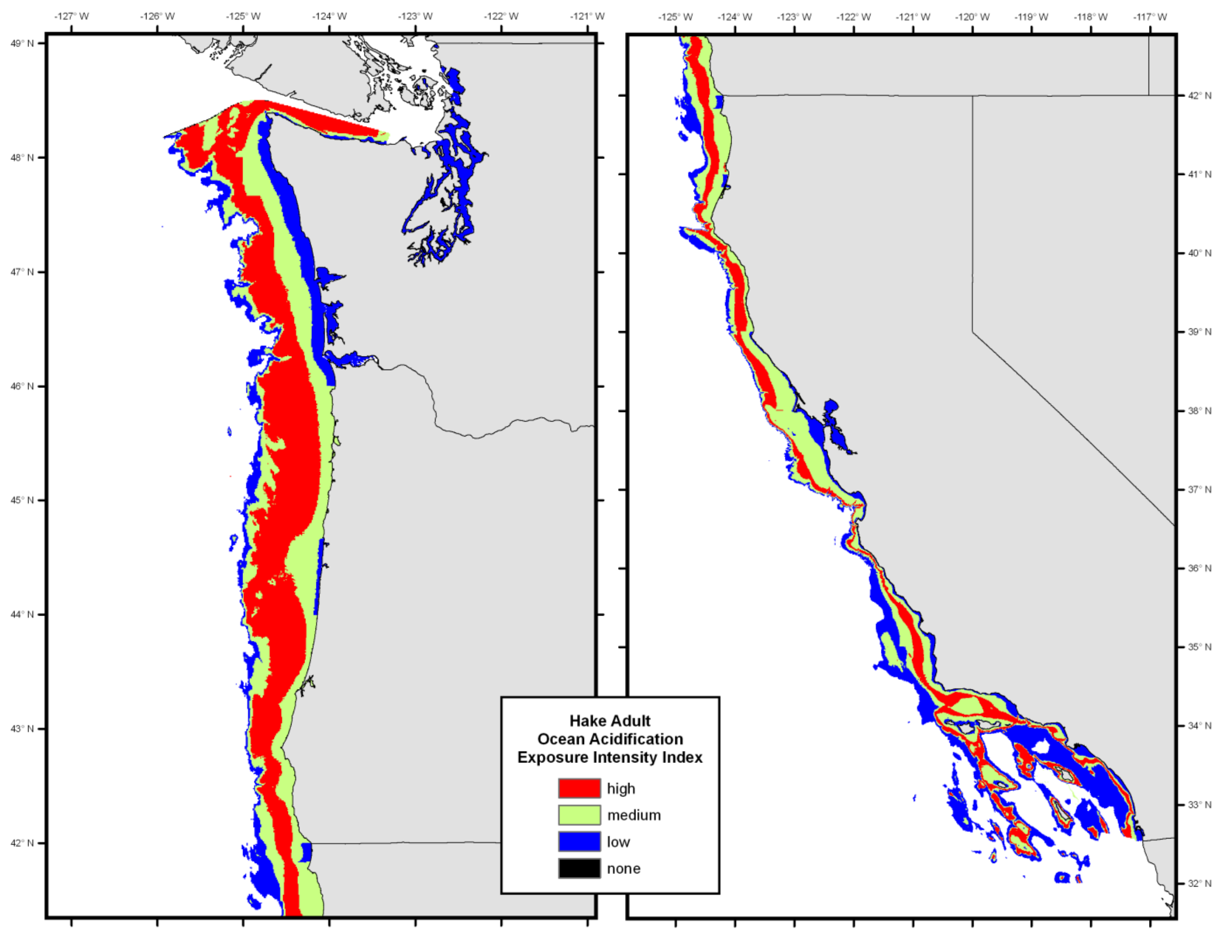

Figure GFR44. Exposure intensity index of ocean acidification for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

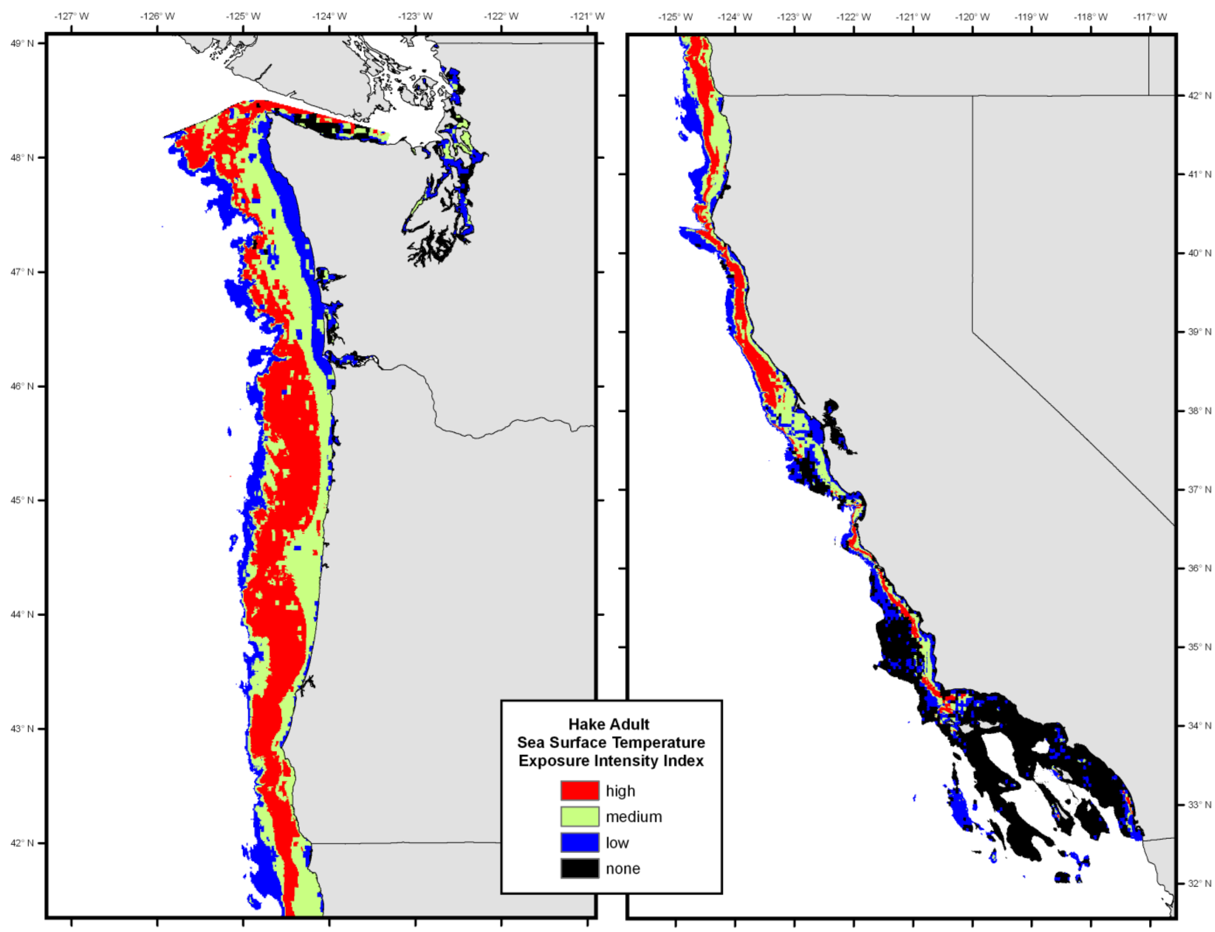

Figure GFR45. Exposure intensity index of sea-surface temperature for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

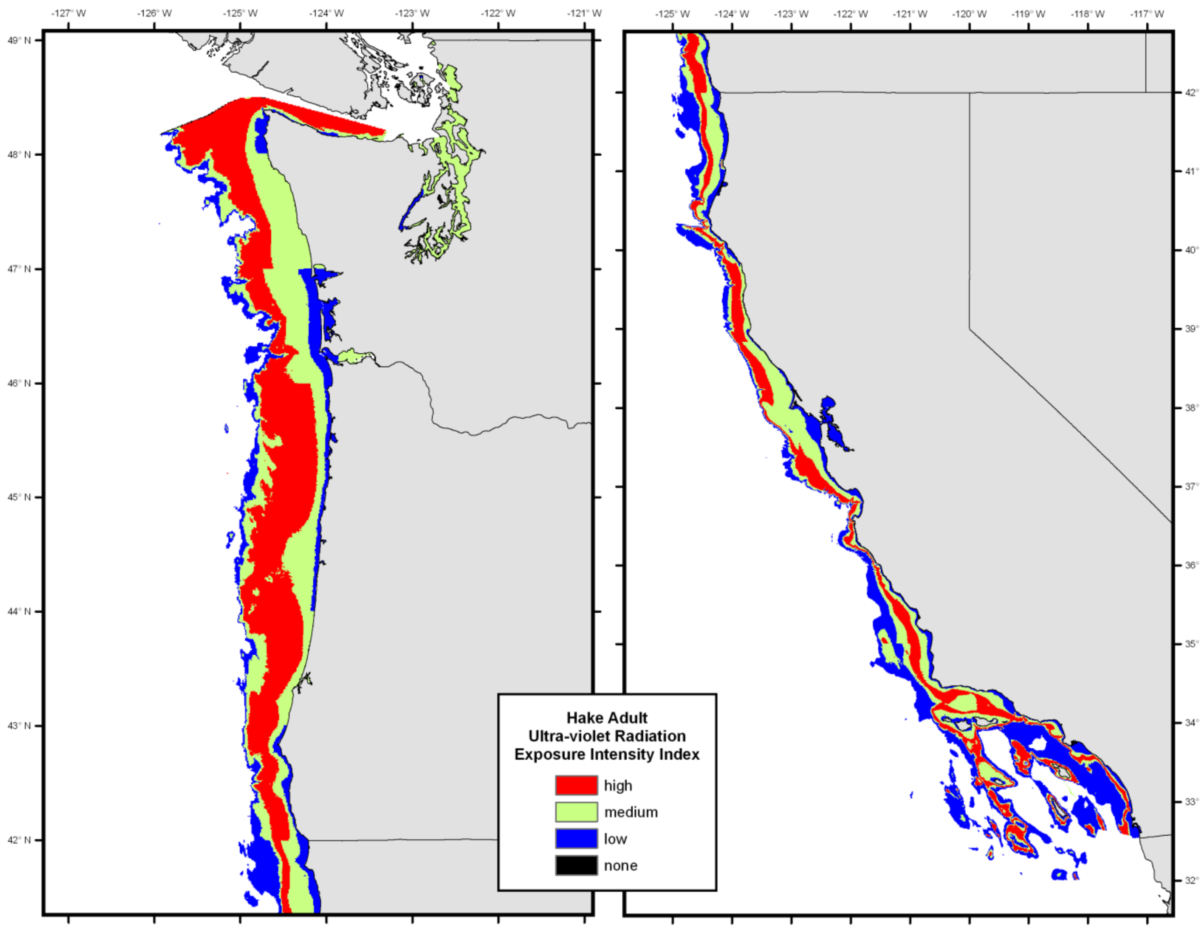

Figure GFR46. Exposure intensity index of ultra-violet radiation for Pacific hake *Merluccius productus* adult. High = upper tercile, Medium = middle tercile, low = lower tercile.

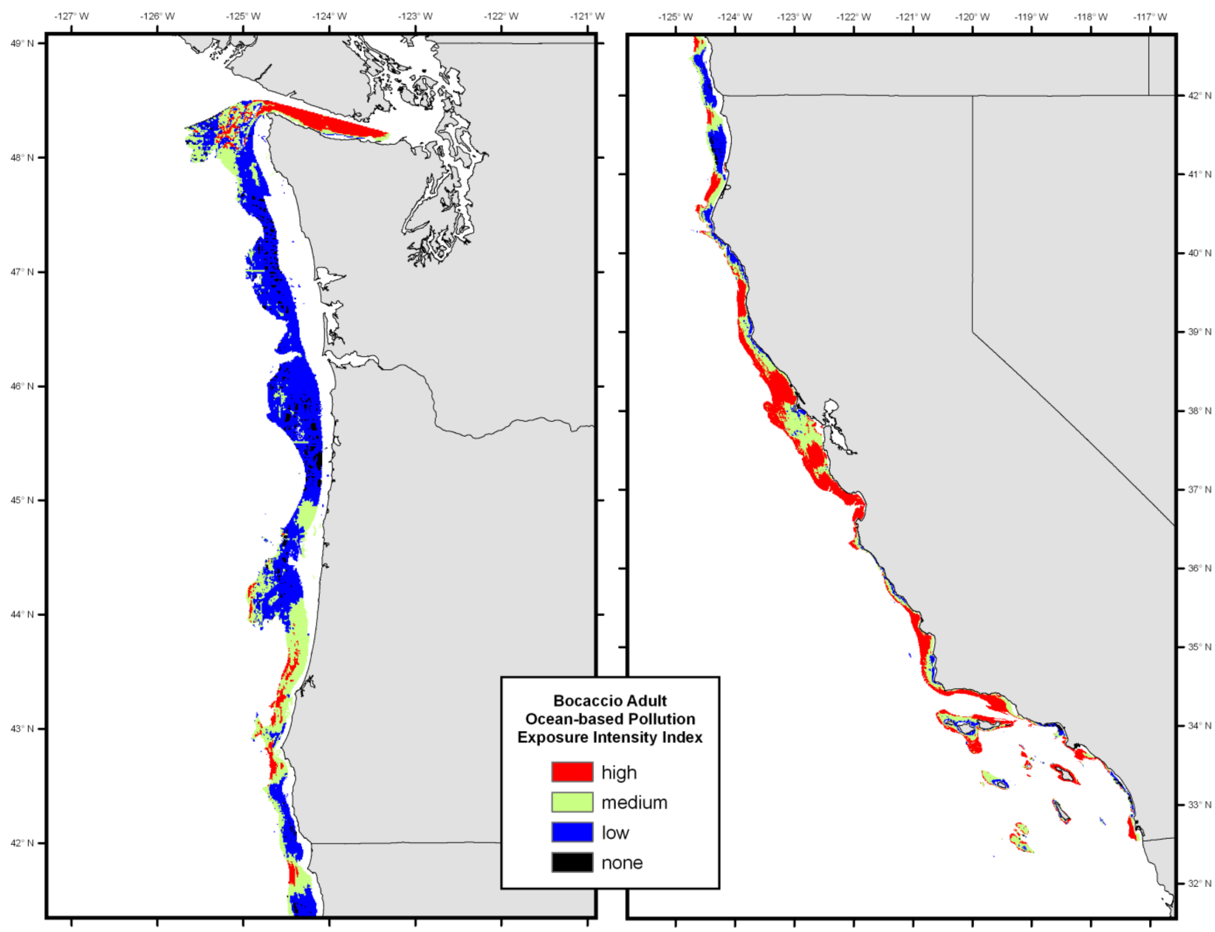

Figure GFR47. Exposure intensity index of ocean-based pollution for bocaccio *Sebastes paucispinis* rockfish adults. High = upper tercile, Medium = middle tercile, low = lower tercile.

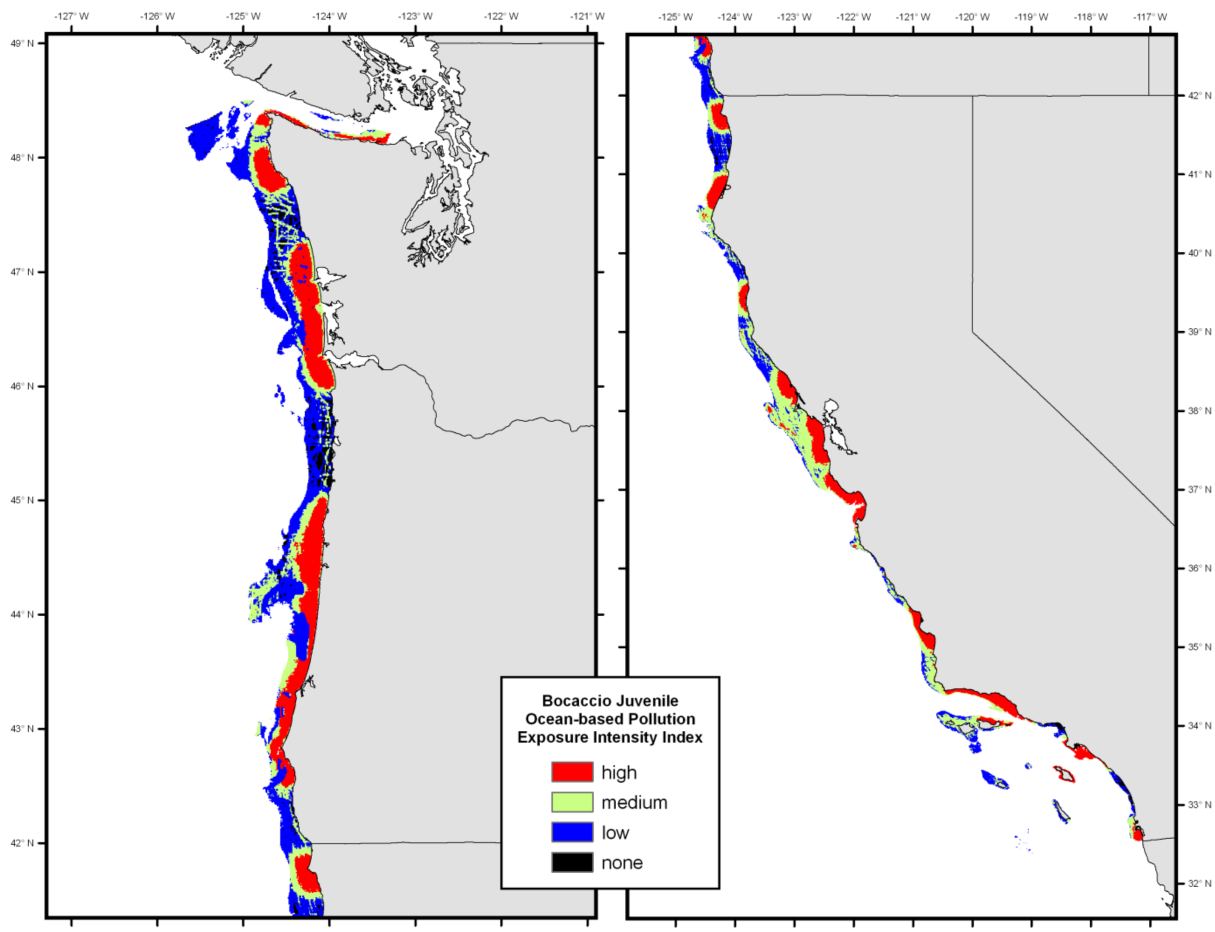

Figure GFR48. Exposure intensity index of ocean-based pollution for bocaccio *Sebastes paucispinis* rockfish juveniles. High = upper tercile, Medium = middle tercile, low = lower tercile.

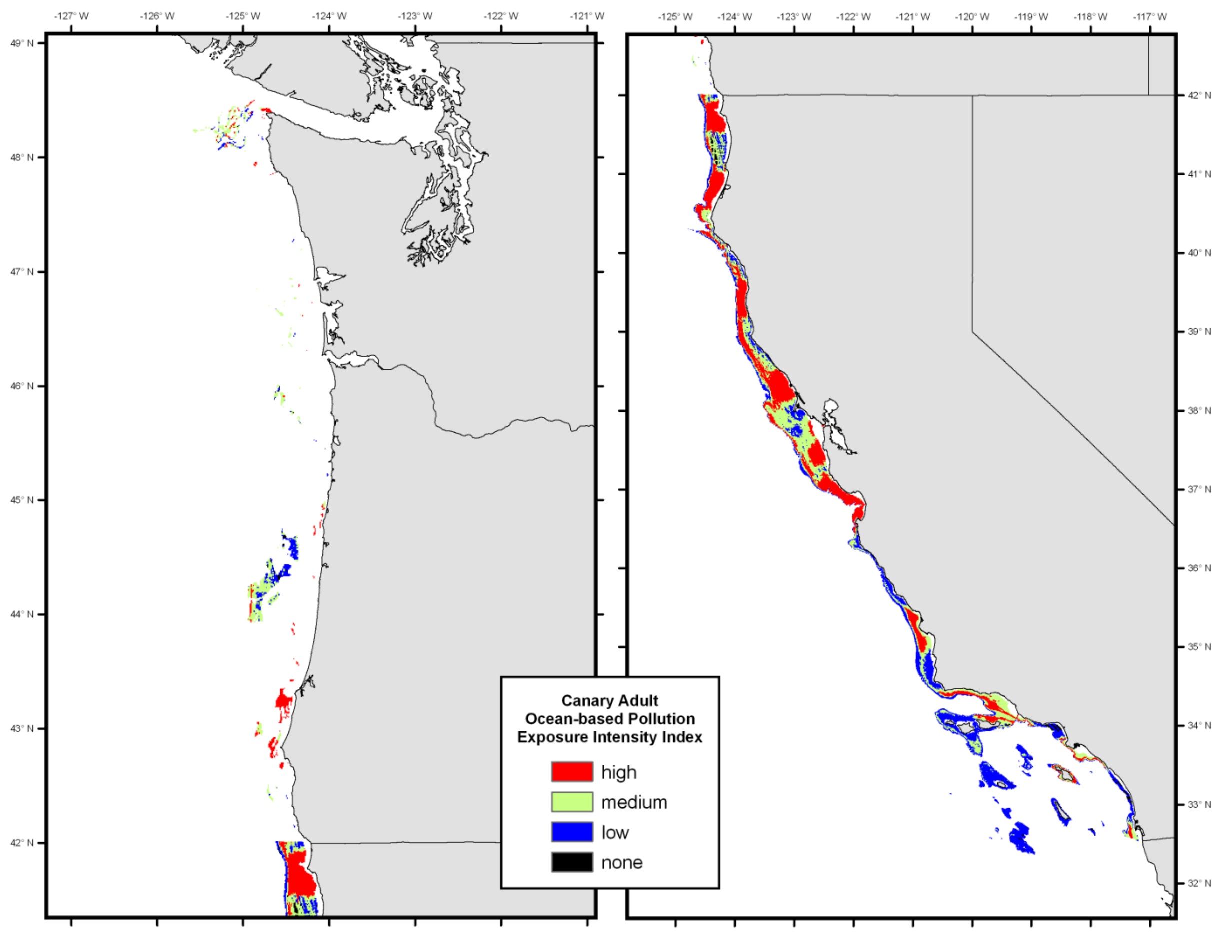

Figure GFR49. Exposure intensity index of ocean-based pollution for canary *Sebastes pinniger* rockfish adults. High = upper tercile, Medium = middle tercile, low = lower tercile.

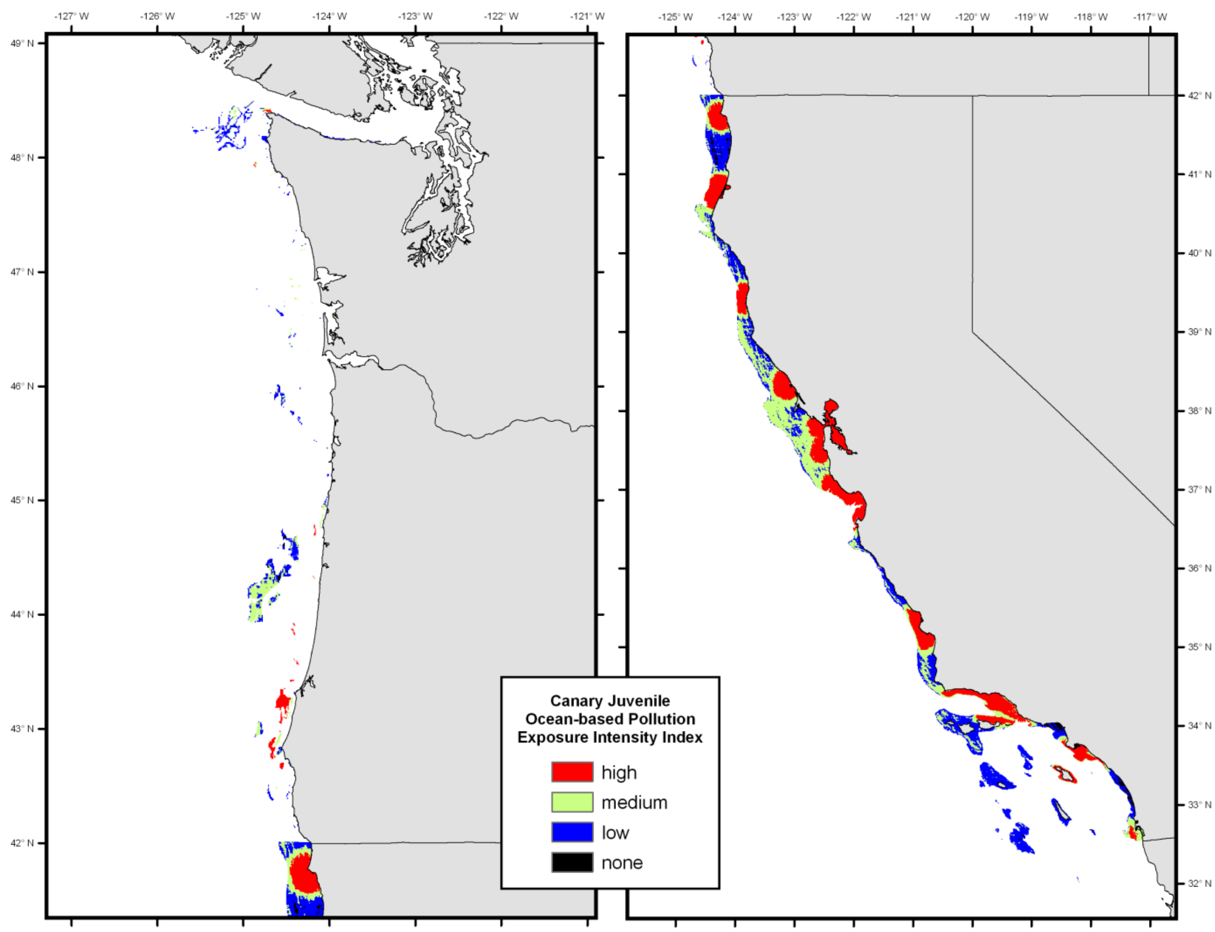

Figure GFR50. Exposure intensity index of ocean-based pollution for canary *Sebastes pinniger* rockfish juveniles. High = upper tercile, Medium = middle tercile, low = lower tercile.

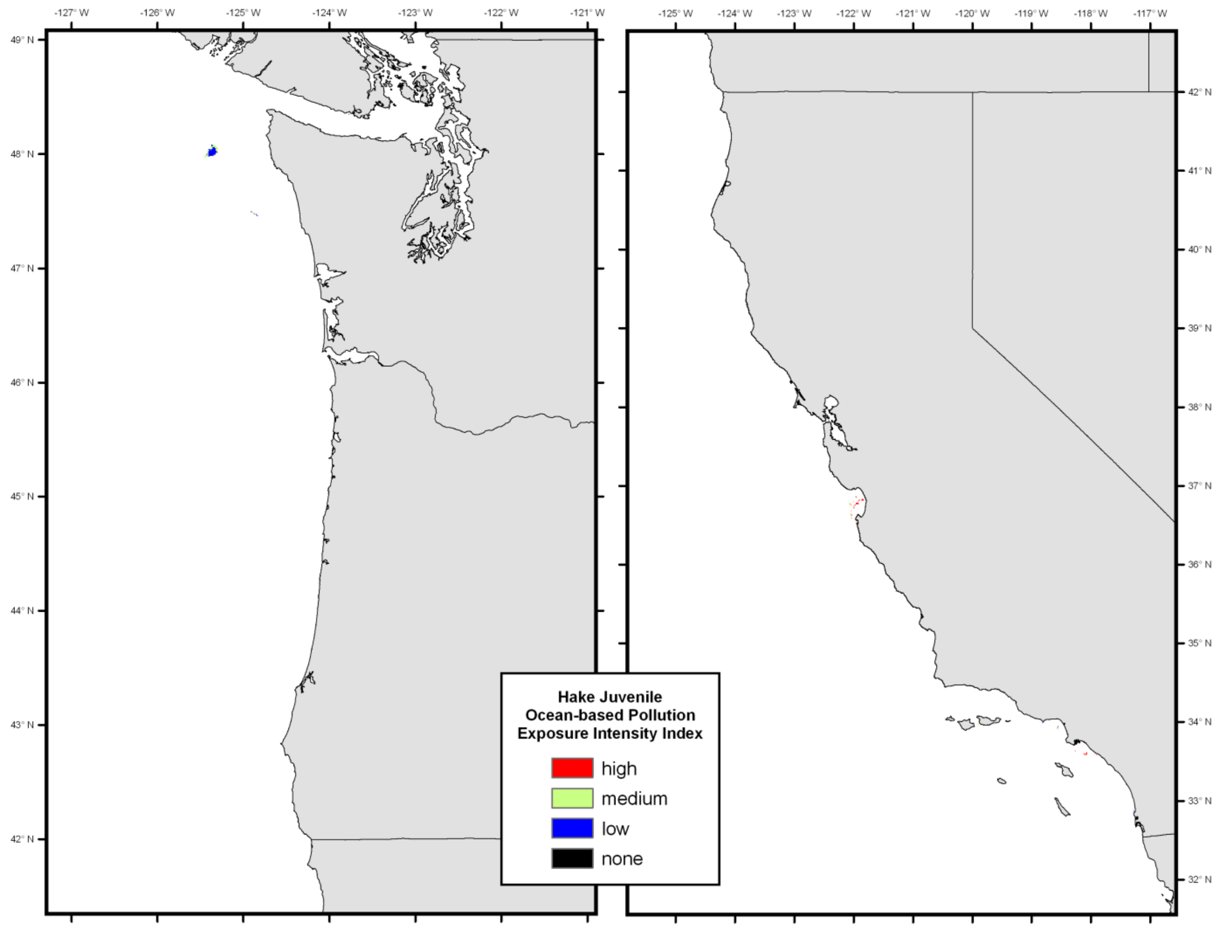

Figure GFR51. Exposure intensity index of ocean-based pollution for Pacific hake *Merluccius productus* juveniles. High = upper tercile, Medium = middle tercile, low = lower tercile.

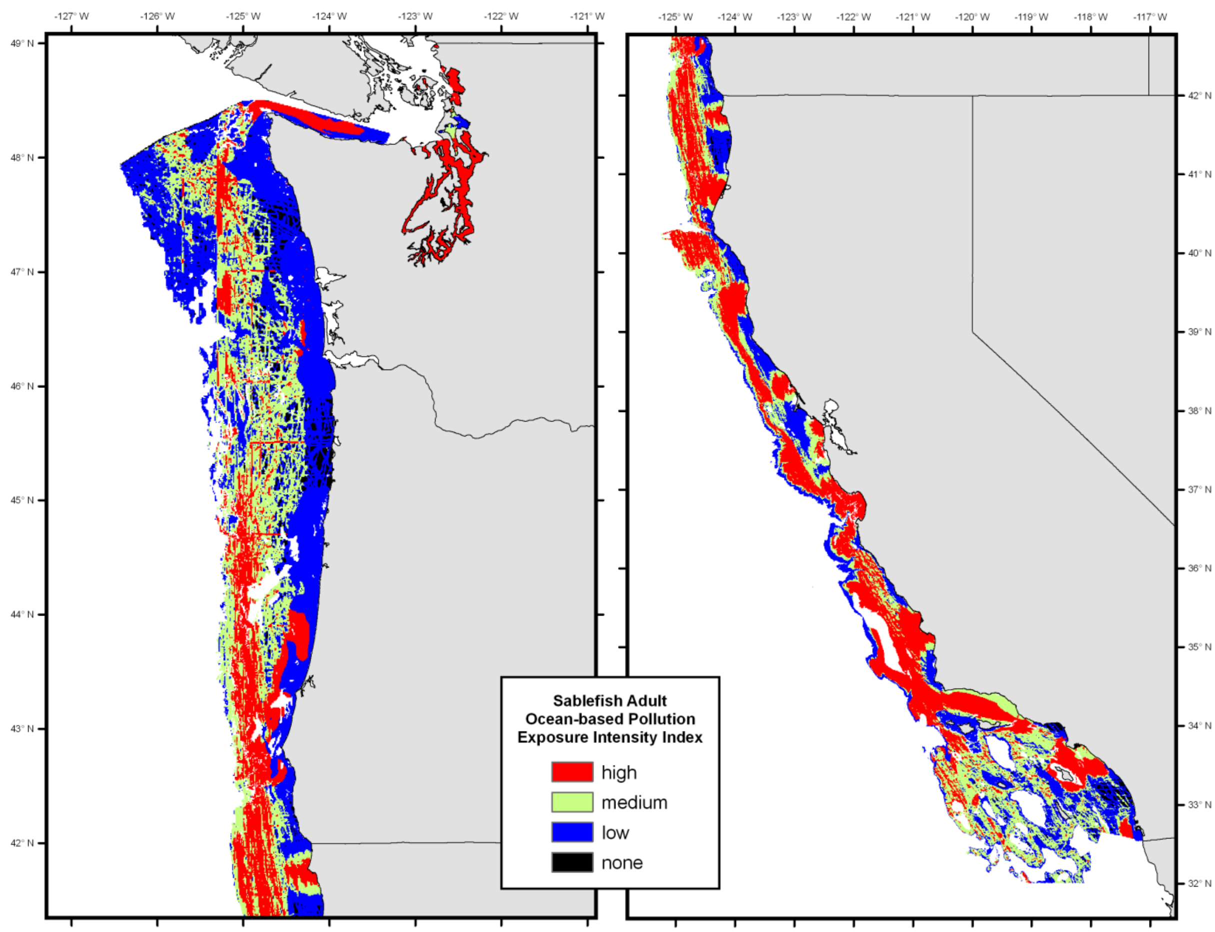

Figure GFR52. Exposure intensity index of ocean-based pollution for sablefish *Anoplopoma fimbria* adults. High = upper tercile, Medium = middle tercile, low = lower tercile.

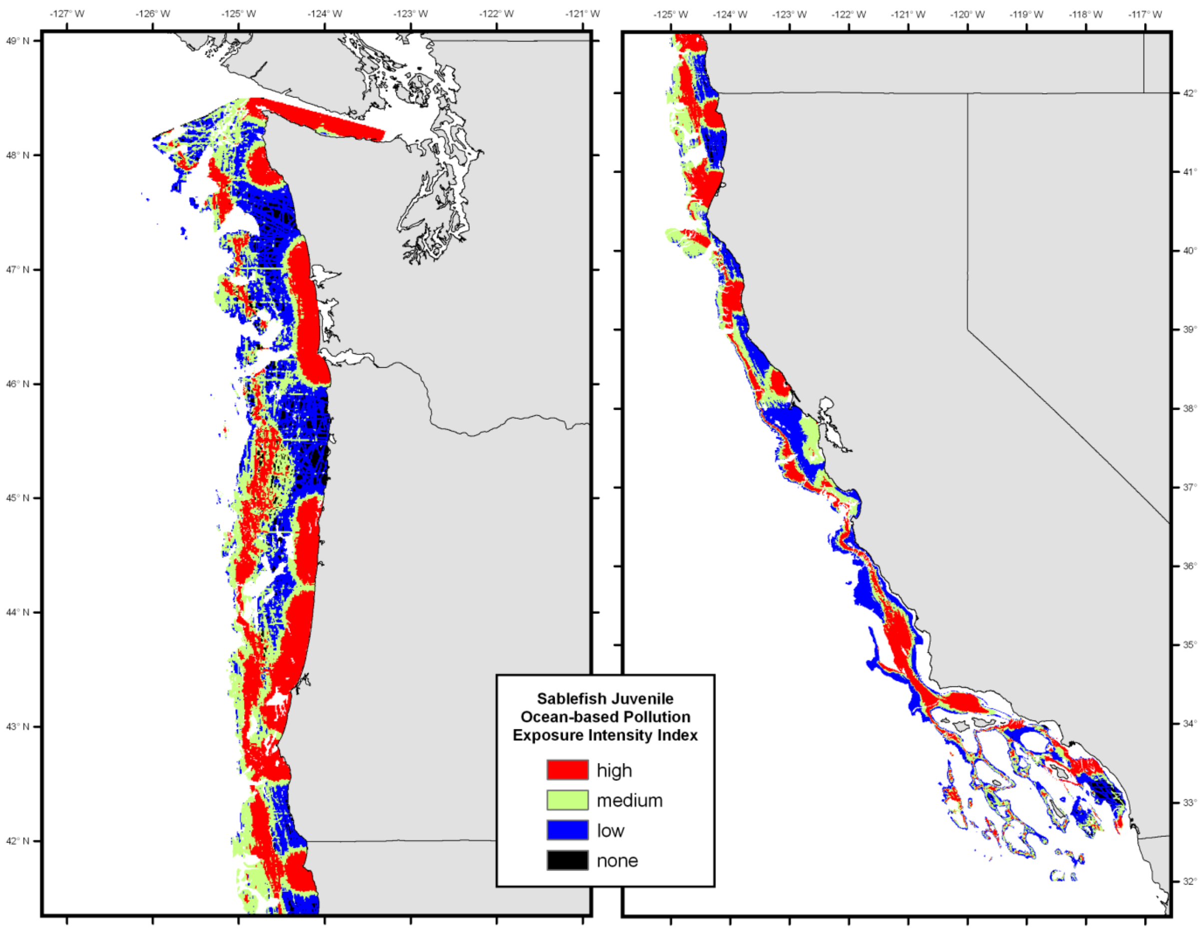

Figure GFR53. Exposure intensity index of ocean-based pollution for sablefish *Anoplopoma fimbria* juveniles. High = upper tercile, Medium = middle tercile, low = lower tercile.

The HSP that we used were developed during the 2005 EFH EIS process. This work is scheduled to be updated every 5 years, so the HSP data that we used in this analysis may be updated in the near future that would improve the underlying data. Of particular interest is the HSP for juvenile Pacific hake (Fig. 6). Currently, the habitat is limited to a few locations. Depending on the definition of 'juvenile', the habitat identified for juvenile hake may be much more expansive than the current analysis.

Detailed information about the development of the data and analytical procedures used to produce the HSPs are described in the document: *Pacific States Marine Fisheries Commission. 2004. Risk Assessment for the Pacific Groundfish FMP*, which is included as Appendix A to the FEIS. Additionally, Appendix D of this document includes a *Report on Updates Made to the Production of Essential Fish Habitat Suitability Probability Maps* (http://www.nwr.noaa.gov/Groundfish-Halibut/Groundfish-Fishery-Management/NEPA-Documents/EFH-Final-EIS.cfm).

The shape files (GIS compatible files) for each species/life-history stage are separated into five geographic regions along the U.S. West Coast due to computer processing limitations during the analysis. We used the 'merge' command in ArcView version 9.3 to combine all regions into one combined data layer. In some of the shape files, polygons were created where HSP equaled 0. This appeared to be due to a few geographic border lines drawn that do not represent changes in HSP values. In order to keep these cells from showing up as habitat ('none' category for exposure intensity index) in further analyses, we changed all the 0 values in each HSP data layer to -9999 (represents 'no data').

NON-FISHERIES THREATS DATA

First, we downloaded the GeoTiff files projected in Arc System Zone 2 for each of the 19 non-fisheries related threats (or impacts) from the National Center for Ecological Analysis and Synthesis's website (http://www.nceas.ucsb.edu/globalmarine/ca_current_data). We created pyramids for each of the files using ArcCatalog version 9.3 and then brought each of the files into ArcView. Each file was then converted into a GRID file using the RasterToOther Conversion tool in the ArcView Toolbox.

For all threats except shipping, we assumed that the threat affected all depths of the water column. For example, if a grid cell had a value of 0.5 for organic pollution, we assumed this threat affected species inhabiting the water column at all depths including the bottom. For shipping, we made a correction to the threat value to take into account that shipping most likely affects the top 20 m of the water column, such that individuals on the bottom are not exposed to this threat. So, we limited the shipping data to depths of 20m or less for bocaccio, canary and sablefish, i.e. for grid cells that were at depths > 20 m, we multiplied the threat value by 0. For Pacific hake, we estimated a proportion of the population that migrates up into the water column at depths less than 20m based on primary literature because most surveys of hake populations do not measure the top 50 m of the water column (D. Chu, Northwest Fisheries Science Center, *pers comm*.). Juvenile hake show vertical distribution into shallow depths of the water column, particularly at night. Sakuma & Ralston (1997) present data showing that ~1/3 of juveniles collected were at 10 m, 1/3 were at 40 m, and 1/3 were found at 100 m); thus, we multiplied the threat value by 0.334 as an estimate of the proportion of juveniles that would be exposed to shipping*. .For adults, some small proportion of adult hake migrate into this depth zone (0-20m) at night, typically feeding on euphausiid populations which are vertically migrating and concentrate near 20 m between 2400-0200 hrs (Alverson & Larkins 1969). Adult hake migrate on a diurnal schedule: fish are dispersed from near surface to 20- m depth at night (10 p.m. to 3 a.m.), descend quickly at dawn and form schools; and rise to the surface at night in 30-40 min (Nelson and

Larkins 1970; Ermakov 1974). These diurnal migrations have been compared to the migrations of their primary prey, euphausiids, as a causal mechanism (Alton and Nelson 1970). Because juveniles are most likely found in the upper water column at greater proportions, we used an estimate of 10% for the proportion of adult hake that migrate into the top 20m of the water column at some point*; therefore, we multiplied the shipping threat values by 0.1 in order to account for this level of exposure.

GROUNDFISH APPENDIX B - NON-FISHERIES THREATS – LITERATURE REVIEW

In the sections below labeled "Threat data layer description, from Halpern et al. (2009)", we have copied information from Halpern et al. (2009) supporting materials; thus, any use of "we" or "our" refers to analyses or work performed by the authors of the original paper.

Information on trends in the threats described below can be found in the Anthropogenic Drivers and Pressures Section of the IEA.

AQUACULTURE

Threat data layer description, from Halpern et al. (2009): Currently no data exist for the location of aquaculture facilities. Google Earth imagery was used to search the coastlines in the California Current for evidence of fish pens. This effort was focused on Puget Sound, Southern California, and Baja, Mexico where aquaculture is known to exist. Data on shellfish aquaculture facilities are not included because they do not exist at this time.

Effects: The impact of aquaculture facilities varies according to the species cultured, the type and size of the operation, and the environmental characteristics of the site (Johnson et al. 2008). Intensive cage and floating netpen systems typically have a greater impact because aquaculture effluent is released directly into the environment. The relative impact of finfish and shellfish aquaculture differs depending on the foraging behavior of the species. Finfish require the addition of a large amount of feed into the ecosystem, which can result in environmental impacts from the introduction of the feed, but also from the depletion of species harvested to provide the feed. Bivalves are filter feeders and typically do not require food additives; however, fecal deposition can result in benthic and pelagic habitat impacts, changes in trophic structure and nutrient and phytoplankton depletion. Aquaculture activities can effect fisheries at both a habitat and species-level. Typical environmental impacts resulting from aquaculture production include: (1) impacts to the water quality from the discharge of organic wastes and contaminants; (2) seafloor impacts; (3) introductions of exotic invasive species; (4) food web impacts; (5) gene pool alterations; (6) changes in species diversity; (7) sediment deposition; (8) introduction of diseases; (9) habitat replacement or exclusion; and (10) habitat conversion (Johnson et al. 2008).

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species). Mortality effects are not likely from the range of current aquaculture activities in the region.

Behavior:3 (juvenile and adult forms of bocaccio and canary rockfish); 2 (juvenile and adult forms of hake and sablefish). Direct negative behavioral effects likely to affect species drawn to habitat structure; from the range of current aquaculture activities in the region, although indirect effects are likely via water quality, light, seafloor and related habitat impact, etc.

Physiology: 2 (juvenile and adult forms of all species). Some negative effects to physiology of all species due to exposure to parasites, nutrient input/fecal coliforms, and chemicals associated with aquaculture/net pen facilities.

ATMOSPHERIC DEPOSITION

Threat data layer description, from Halpern et al. (2009) : We used the atmospheric deposition of sulfates derived from the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/), processed in the same manner as for nitrogen as described above in 'Nutrient Input'. We used sulfate deposition as a proxy measure for the distribution and deposition of all atmospheric pollutants.

Effects: Substances such as sulfur dioxide, nitrogen oxide, carbon monoxide, lead, volatile organic compounds, particulate matter, and other pollutants are returned to the earth through either wet or dry atmospheric deposition (Johnson et al. 2008). Atmospheric pollution is a major source of many nutrient, chemical, and heavy metal pollutants whose sources can be far away from the marine ecosystems being impacted. See pollutants, above.

SENSITIVITY SCORES

Mortality: 3 (juvenile forms of all species); 2 (adult forms of all species). Scored as if inorganic/organic pollution; Sensitivity scores reflect that most fish species are particularly sensitive to contaminants/pollution during early life history.

Behavior: 2 (juvenile and adult forms of all species) There is no apparent behavioral response that would reduce or increase sensitivity to this threat.

Physiology: 3 (juvenile forms of all species); 2 (adult forms of all species). Body size, age, feeding ecology, and trophic position are some of the most important factors determining bioaccumulation in marine fishes. Most species have no apparent physiological response (i.e. they do not metabolize these pollutants to remove them) that would reduce sensitivity to this threat.

COASTAL ENGINEERING

Coastal engineering Threat data layer description, from Halpern et al. (2009) : Coastal engineering represents shore hardening of various kinds, including riprap walls, cement walls (for harbors, sediment containment, etc.), and jetties and piers. For coastlines within the United States, we extracted data from NOAA's Environmental Sensitivity Index (ESI) for California, Puget Sound and Columbia River regions (http://response.restoration.noaa.gov) and from The Nature Conservancy's (TNC) Pacific Northwest coast ecoregional assessment geodatabase (Ferdaña et al. 2006) for Oregon and Washington. These databases classify linear segments of coast into ecosystem types and also report location of hardened shorelines. For Baja, Google Earth images were generally at high enough resolution to be able to identify human-modified shorelines, but where they were not we assumed no coastal engineering exists.

Effects: Coastal engineering structures destroy the habitat directly under them and can significantly modify surrounding ecosystems through changes in circulation patterns and sediment transport (National Research Council 2007; Halpern et al. 2009b; Shipman et al. 2010). Any structural modification of the shoreline will alter several important physical processes, and can therefore be considered an impact (Williams and Thom 2001). For the most part, impact potential can be related to the size and location of the structure and the types of physical processes it alters. Impacts may be considered direct or indirect. Direct impacts are generally associated with construction activities, including excavation, burial, and various types of pollution. Indirect impacts occur following physical disturbance, and are chronic in nature due to permanent alteration of physical processes such as sediment transport and wave energy. "Cumulative impacts" are associated with increasing number or size of indirect or direct impacts, which can have either linear or non-linear cumulative responses. Many shoreline "hardening" structures, such as seawalls and jetties, tend to reduce the complexity of habitats and the amount of intertidal habitats (Williams and Thom 2001). Differences in fish behavior and usage between modified and unmodified shorelines are caused by physical and biological effects of the modifications, such as changes in water depth, slope, substrate, and shoreline vegetation (Toft et al. 2007).

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species). We assume most of the chronic effects of coastal engineering structures on fishes will be behavioral in nature.

Behavior: 3 (juvenile and adult forms of bocaccio and canary rockfish); 2 (juvenile and adult forms of hake, juvenile form of sablefish); 1 (adult form of sablefish). Most coastal engineering impacts will affect behavior of species highly dependent on benthic habitat structure (i.e., rockfish would be attracted to structure; flatfish would avoid structure). Direct effects of construction activity (noise, disturbance) would cause avoidance behavior for all species

Physiology: 2 (juvenile and adult forms of all species). We assume most of the chronic effects of coastal engineering structures on fishes will be behavioral in nature.

DIRECT HUMAN IMPACTS

Threat data layer description, from Halpern et al. (2009) : To estimate the impact of this source of stress, we employed a 3 step process. First, we collected annual beach attendance data that are available for 98 beaches in Central and Southern California (Kildow and Colgan 2005; Dwight et al. 2007)(http://www.parks.ca.gov/?page_id=23308). Of these, only 59 have additional information on fees, facilities, and parking availability. U.S. beach access points in the California Current are reported in the MLPA database for California (http://marinemap.org/mlpa), the Oregon Geospatial Enterprise Office (http://gis.oregon.gov/DAS/EISPD/GEO/alphalist.shtml), and Washington State Department of Ecology BEACH (Beach Environmental Assessment, Communication and Health) Program (http://www.doh.wa.gov/ehp/TS/WaterRec/beach/default.htm). Second, we used these actual beach attendance data to develop a predictive model of beach visitation for all access points without recorded data. Predictor variables included number of parking spaces (park), entrance fee (fee), available facilities (facils: a yes/no variable) and number of people with 50 miles of the access point (pop). Fifty miles was chosen because studies of beach attendance (in southern California) suggest most visitors are local and travel 50-80 miles from home to get to the beach (Dwight et al. 2007; Nelsen et al. 2007). Population density data come from the LandScan project (http://www.ornl.gov/sci/landscan/index.html) and are reported at 1km^2 resolution. We implemented a backwards selection procedure of a multivariate linear model on these variables, and used AIC to select the best model. The final model for predicting annual beach access (BA) was BA = 0.1706(pop) – 16840 ($F = 9.743$, $df = 2{,}94$, $p < 0.001$, adjusted $R^2 = 0.15$). We then applied this model to all beach access points without real attendance data. These annual beach access values were then used as estimates of the relative intensity of direct human impact on that pixel of coastline. Beach access point data were not available for Baja, so this impact was not estimated along the Mexican coastline.

Effects: People visiting beaches and coastal areas can impact intertidal and nearshore ecosystems through direct trampling or by disturbing or displacing species that would normally use those locations. None of these species are sessile intertidal inhabitants and therefore they would not be subject to this type of disturbance.

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species). Trampling and disturbance is not likely to affect species in water column or near bottom.

Behavior: 1 (juvenile and adult forms of all species) Trampling and disturbance is not likely to affect species in water column or near bottom.

Physiology: 2 (juvenile and adult forms of all species). The physiological response to trampling and disturbance does not change sensitivity to this threat.

INORGANIC POLLUTION

Inorganic pollution Threat data layer description, from Halpern et al. (2009): Inorganic pollution into coastal marine waters was estimated from two sources, point source pollution from factories and mines and non-point source pollution that scales with the amount of impervious (hardened) surface area. Point source data are reported in the EPA Toxics Release Inventory (http://www.epa.gov/tri/). We multiplied the amount of each chemical released on-site to the ground or water (excluding aerial releases, off-site transfers, treated and recycled chemicals) by its toxicity (reported by the Indiana Clean Manufacturing Technology and Safe Materials Institute (ICMTSM) in its Indiana Relative Chemical Hazard Score (IRCHS): https://engineering.purdue.edu/CMTI/IRCHS/) to produce a weighted amount of inorganic pollution release from each source, and summed all values within each watershed. For those chemical compounds not listed in the IRCHS database, we applied the average score from the class of chemicals to which the missing chemical. Impervious surface area (ISA) data were processed as in the global project (Halpern et al. 2008), using the global impervious surface area data layer developed by the U.S. National Geophysical Data Center for the years 2000-2001 (http://www.ngdc.noaa.gov/dmsp/download_global_isa.html) as a proxy measure for the use and input of inorganic pollutants. The %-coverage of impervious area in each $1km^2$ pixel was identified, and the average %-coverage for all $1km^2$ pixels within a watershed is multiplied by the number of pixels to produce a total area (km^2) of impervious surface within each watershed. Point source and ISA estimates of inorganic pollution in each watershed were then log-transformed and normalized (described below) separately, and then the two layers were summed and re-normalized to create a single inorganic pollution value for each watershed. These values were then assigned to the pour-point for each watershed.

Effects: While all pollutants can become toxic at high enough levels, there are a number of compounds that are toxic even at relatively low levels (Johnson et al. 2008). The US Environmental Protection Agency (US EPA) has identified and designated more than 126 analytes as "priority pollutants." According to the US EPA, "priority pollutants" of particular concern for aquatic systems include: (1) dichlorodiphenyl trichloroethane (DDT) and its metabolites; (2) chlorinated pesticides other than DDT (e.g., chlordane and dieldrin); (3) polychlorinated biphenyl (PCB) congeners; (4) metals (e.g., cadmium, copper, chromium, lead, mercury); (5) polycyclic aromatic hydrocarbons (PAHs); (6) dissolved gases (e.g., chlorine and ammonium); (7) anions (e.g., cyanides, fluorides, and sulfides); and (8) acids and alkalis. While acute exposure to these substances produce adverse effects of aquatic biota and habitats, chronic exposure to low concentrations probably is a more significant issue for fish population structure and may result in multiple substances acting in "an additive, synergistic or antagonistic manner" that may render impacts relatively difficult to discern (Johnson et al. 2008).

Coastal/estuarine pollution can affect any life stage of fish, but fish can be particularly sensitive to toxic contaminants during the first year of life. Effects of pollutants on reproduction, recruitment, behavior, and survival may be particularly critical; e.g., survival may be reduced by inherited and dietary contaminants such as PCBs; reproductive rate may be a more sensitive parameter than survival.

The negative impacts of pollution on commercial fish stocks have generally not been demonstrated, largely due to the fact that only drastic changes in marine ecosystems are detectable and the difficulty in distinguishing pollution induced changes from those due to other causes (Sinderman 1994). Normally chronic and sublethal changes take place very slowly and it is impossible to separate natural fluctuations from anthropogenically caused ones. Furthermore, fish populations themselves are estimated only imprecisely, so the ability to detect and partition contaminant effects is made even more difficult.

SENSITIVITY SCORES

Mortality: 3 (juvenile forms of all species); 2 (adult forms of all species); Scoring based on assumption that most fishes are particularly sensitive to contaminants/pollution during their early life history.

Behavior: 2 (juvenile and adult forms of all species). Response behavior to inorganic pollution does not change (i.e., no avoidance) susceptibility to the toxic effects of these pollutants.

Physiology: 2 (juvenile forms of all species); 3 (adult forms of all species). Body size, age, feeding ecology, and trophic position are some of the most important factors determining bioaccumulation in marine fishes. Most species have no apparent physiological response (i.e. they do not metabolize these pollutants to remove them) that would reduce sensitivity to this threat.

LIGHT POLLUTION

Threat data layer description, from Halpern et al. (2009): Species that use coastal habitats can be impacted by noise and light pollution that emerges from coastal human populations. To estimate the distribution of this stressor, we used the stable lights at night database (http://www.ngdc.noaa.gov/dmsp/global_composites_v2.html) and isolated the light coming from coastal land area (that can be seen in ocean pixels) and offshore oil rigs (both sources of light do not move from night to night and so can be isolated, which NGDC has already processed). The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for 2003.

Effects: Ecological light pollution has demonstrable effects on the behavioral and population ecology of organisms in natural settings. As a whole, these effects derive from changes in orientation, disorientation, or misorientation, and attraction or repulsion from the altered light environment, which in turn may affect foraging, reproduction, migration, and communication. (Longcore and Rich 2004). Juvenile sablefish exposed to a horizontal light gradient exhibited an avoidance of bright light (Sogard and Olla 1998). While juvenile sablefish were primarily surface-oriented, they nonetheless displayed clear day/night differences in vertical distribution. Proximity to the surface and low activity at night contrasted with higher activity and the greater range of vertical movement that typified daytime behavior. Movement throughout the water column during the day and the negative phototaxis observed in a horizontal gradient suggests that juveniles in nature, at least during the day, may not be restricted to the neuston.

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species); Light pollution is generally not considered a stressor leading to the indirect/direct mortality of any of these species.

Behavior:2 (juvenile and adult forms of bocaccio, canary rockfish, and hake); 1 (juvenile and adult forms of sablefish). Light pollution may cause some behavioral changes, such as avoidance, predator interactions, or vertical migration. Species like sablefish, which exhibit negative phototactic responses to artificial light, show a behavioral response that would reduce their sensitivity to this threat.

Physiology: 2 (juvenile and adult forms of all species). Light pollution causes minor to little physiological changes in fishes.

NUTRIENT INPUT

Nutrient Threat data layer description, from Halpern et al. (2009) : Nutrient input (considering nitrogen only here) comes primarily from three sources: farming (fertilizer application and animal farm runoff), sewage, and atmospheric deposition. Because sewage input is generally very difficult to document across larger scales, only nitrogen input from farming and atmospheric deposition was quantified. County-level fertilizer application data come from the USGS (source: "Vulnerability of Shallow Groundwater and Drinking-water Wells to Nitrate in the United States" by Bernard T. Nolan and Kerie J. Hitt) and report average annual nitrogen input from 1992-2001 in kgs/hectare. Confined manure (primarily from dairy farms) is from the same source and reported in the same units, but for the years 1992-1997. Atmospheric wet deposition of pollutants is recorded at over 100 stations within the U.S. as part of the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/); data from the 19 stations along the west coast and in the Aleutian Islands was used along with spatially kriged values between the stations over the landscape and onto the waters of the California Current (including Baja), measured in kgs/yr/km^2.

Effects: While much of the excess nutrients within coastal waters originates from sewage treatment plants, nonpoint sources of nutrients from municipal and agricultural run-off, contaminated groundwater and sediments, septic systems, wildlife feces, and atmospheric deposition from industry and automobile emissions contribute significantly (Johnson et al. 2008). Failing septic systems contribute to non-point source pollution and are a negative consequence of urban development. The US EPA estimates that 10- 25%

of all individual septic systems are failing at any one time, introducing feces, detergents, endocrine disruptors, and chlorine into the environment. Sewage waste contains significant amounts of organic matter that cause a biochemical oxygen demand, leading to eutrophication of coastal waters.

Severely eutrophic conditions may adversely affect aquatic systems in a number of ways, including: reductions in submerged aquatic vegetation (SAV) through reduced light transmittance, epiphytic growth, and increased disease susceptibility; mass mortality of fish and invertebrates through poor water quality; and alterations in long-term natural community dynamics.

SENSITIVITY SCORES

Mortality: 2 (juvenile forms of all species); 1 (adult forms of all species). Scoring is based on assumption that fish are particularly sensitive (mortality) from eutrophic conditions / hypoxia early in their life history.

Behavior: 1 (juvenile and adult forms of all species). Avoidance response behavior to hypoxia from nutrient pollution likely increases population fitness. (Bell and Eggleston 2005)

Physiology: 2 (juvenile and adult forms of all species). Juvenile and adult fish are both sensitive to physiological effects of hypoxia that is often associated with nutrient loading in aquatic habitats. (Sinderman 1995)

OCEAN-BASED POLLUTION

Threat data layer description, from Halpern et al. (2009) : Ocean-based pollution is assumed to derive from two primary sources, commercial shipping and ports, as was done in the global project (Halpern et al. 2008). We used the shipping data described above in combination with port volume data derived largely de novo for the California Current. In all cases we used data for, or projected to, the year 2003 as this was when the largest amount of data was available. Commercial port tonnage and location data for US ports came from the US Army Corps of Engineers Navigation Data Center: http://www.iwr.usace.army.mil/ndc/wcsc/portname03.htm. Commercial port location data for ports in Mexico or Canada came from the Princeton University Library Digital Map and Geospatial Information Center: http://www.princeton.edu/~geolib/gis/index.html, with tonnage for Canadian ports from Transport Canada (http://www.tc.gc.ca/pol/en/report/anre2005/8F_e.htm) and tonnage for Mexican ports from the global project (Halpern et al. 2008). Non-commercial ports and their modeled ship traffic (measured in tonnage, but related to port facilities; see (Halpern et al. 2008)) were included from the global project. All port layers were then combined into a single layer, and this layer (log-transformed and normalized) and the shipping layer were combined and then renormalized to create a single pollution layer.

Effects: Marine trash may be ingested by some fish species, resulting in mortality, although this is most prominently reflected in the bird and sea turtle literature (Derraik 2002). The behavioral effects of marine trash or debris may be t concentrate fish both at the water's surface (FAD – floating aggregation devices) and on the bottom (artificial reefs).

SENSITIVITY SCORES

Mortality: 2 (juvenile and adult forms of all species). Scored as if solid trash/debris from commercial operations. Most likely effects of solid trash would be from ingestion or entanglement, but there are few good examples in the literature for fishes.

Behavior: 2 (juvenile and adult forms of bocaccio and canary rockfish); 2 (juvenile and adult forms of hake and sablefish). Most likely behavioral effects of solid trash would be attraction to sunken or floating debris by structure-associated species, such as rockfish, and avoidance by structure-averse species. Other species/forms would not change their behavior.

Physiology: 2 (juvenile and adult forms of all species). Scored as if solid trash/debris from commercial operations. No physiological response that would affect sensitivity to marine trash.

OFFSHORE OIL ACTIVITIES

Threat data layer description, from Halpern et al. (2009): Offshore oil rigs in the California Current are exclusively found in southern California. We obtained location information for these rigs using the same methods as described in the global project (Halpern et al. 2008), producing a total of 27 oil rigs. These locations were confirmed with the data from the California MLPA (http://marinemap.org/mlpa).

Effects: The environmental risks posed by offshore exploration and production are well known. They include the loss of hydrocarbons to the environment, smothering of benthos, sediment anoxia, destruction of benthic habitat, and the use of explosives (Macdonald et al. 2002). Petroleum exploration involves seismic testing, drilling sediment cores, and test wells in order to locate potential oil and gas deposits (Johnson et al. 2008). Petroleum production includes the drilling and extraction of oil and gas from known reserves. Oil and gas rigs are placed on the seabed and as oil is extracted from the reservoirs, it is transported directly into pipelines. While rare, in cases where the distance to shore is too great for transport via pipelines, oil is transferred to underwater storage tanks. From these storage tanks, oil is transported to shore via tanker. According to the MMS, there are 21,000 miles of pipeline on the United States OCS. According to the National Research Council (NRC), pipeline spills account for approximately 1,900 tonnes per year of petroleum into US OCS waters, primarily in the central and western Gulf of Mexico. Other potential negative impacts include: physical damage to existing benthic habitats within the "drop zone", undesired changes in marine food webs, facilitation of the spread of invasive species, and release of contaminants as rigs corrode (Macreadie et al. 2011).

However, the effects of oil rigs on fish stocks is less conclusive, with these risks balanced out by the possible enhanced productivity brought about by colonization of novel habitats by structure-associated fishes and invertebrates (e.g., rockfish, encrusting organisms, etc.) (Love et al. 2006). Decommissioned rigs could enhance biological productivity, improve ecological connectivity, and facilitate conservation/restoration of deep-sea benthos (e.g. cold-water corals) by restricting access to fishing trawlers. Preliminary evidence indicates that decommissioned rigs in shallower waters can also help rebuild declining fish stocks. Petroleum extraction and transportation can lead to a conversion and loss of habitat in a number of other ways. Activities such as vessel anchoring, platform or artificial island construction, pipeline laying, dredging, and pipeline burial can alter bottom habitat by altering substrates used for feeding or shelter. Disturbances to the associated epifaunal communities, which may provide feeding or shelter habitat, can also result. The installation of pipelines associated with petroleum transportation can have direct and indirect impacts on offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats. The destruction of benthic organisms and habitat can occur through the installation of pipelines on the sea floor (Gowen 1978). Benthic organisms, especially prey species, may recolonize disturbed areas, but this may not occur if the composition of the substrate is drastically changed or if facilities are left in place after production ends. (Johnson et al. 2008).

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species). Effects of oil rigs would be primarily based on direct impacts, novel structure, noise, and addition of potential pollutants. Effects would more likely be behavioral than mortality-based effects (Macreadie et al. 2011)

Behavior:3 (juvenile and adult forms of bocaccio and canary rockfish); 2 (juvenile and adult forms of hake, juvenile form of sablefish); 1 (adult form of sablefish). Mixed effects, depending on species and location, but more likely behavioral than mortality-based effects (Macreadie et al. 2011); more likely beneficial to rockfish, which are associated with structures.

Physiology: 2 (juvenile and adult forms of all species). Mixed effects, depending on species and location, but more likely behavioral than mortality-based effects (Macreadie et al. 2011). There is no physiological response that would enhance or reduce the sensitivity of these species to oil rigs.

ORGANIC POLLUTION

Organic pollution Threat data layer description, from Halpern et al. (2009) (Halpern et al. 2009a): Dasymetric mapping techniques (Halpern et al. 2008) were used to estimate input rates based on national level statistics and land-use categories. Land cover data came from the U.S. Geologic Survey (http://edcsns17.cr.usgs.gov/glcc/) for the US and Baja and from the National Atlas of Canada (http://atlas.nrcan.gc.ca/site/english/index.html) for those watersheds. Pesticide use statistics were reported for the US by the National Center for Food and Agricultural Policy 1997 Summary Report and by Environment Canada's Survey of Pesticide Sales and Use in British Columbia for the year 1999. These values were then distributed onto the landscape using dasymetric mapping techniques to get annual pesticide use per km^2. Values for Baja, Mexico were taken from the global project (Halpern et al. 2008). Data were also available at the county level within the State of California, and so we reran the dasymetric mapping for California using these county data and then compared the output to that from the national level data to test the accuracy of the broader model.

Effects: [in addition to the general pollution effects described under inorganic pollution, above. Much of the following is taken from Johnson et al. (2008)].

Pesticides - There are three basic ways that pesticides can adversely affect the health and productivity of fisheries: (1) direct toxicological impact on the health or performance of exposed fish; (2) indirect impairment of the productivity of aquatic ecosystems; and (3) loss or degradation of habitat (e.g., aquatic vegetation) that provides physical shelter for fish and invertebrates (Johnson et al. 2008). For many marine organisms, the majority of effects from pesticide exposures are sublethal, meaning that the exposure does not directly lead to the mortality of individuals. Sublethal effects can be of concern, as they impair the physiological or behavioral performance of individual animals in ways that decrease their growth or survival, alter migratory behavior, or reduce reproductive success. Early development and growth of organisms involve important physiological processes and include the endocrine, immune, nervous, and reproductive systems. Many pesticides have been shown to impair one or more of these physiological processes in fish. For example, evidence has shown that DDT and its chief metabolic by-product, dichlorodiphenyl dichloroethylene (DDE), can act as estrogenic compounds, either by mimicking estrogen or by inhibiting androgen effectiveness. DDT has been shown to cause deformities in winter flounder eggs and Atlantic cod embryos and larvae. Generally, however, the sublethal impacts of pesticides on fish health are poorly understood. The direct and indirect effects that pesticides have on fish and other aquatic organisms can be a key factor in determining the impacts on the structure and function of ecosystems. This factor includes impacts on primary producers and aquatic microorganisms, as well as macroinvertebrates that are prey species for fish. Because pesticides are specifically designed to kill insects, it is not surprising that these chemicals are relatively toxic to insects and crustaceans that inhabit river systems and estuaries.

PAH - Petroleum products, including polycyclic aromatic hydrocarbons (PAH), consist of thousands of chemical compounds which can be particularly damaging to marine biota because of their extreme toxicity, rapid uptake, and persistence in the environment (Johnson et al. 2008). PAH have been found to be significantly higher in urbanized watersheds when compared to nonurbanized watersheds. Low-level chronic exposure to petroleum components and byproducts (i.e., polycyclic aromatic hydrocarbons [PAH]) have been shown in Atlantic salmon (*Salmo salar*) to increase embryo mortality, reduce growth, and lower the return rates of adults returning to natal streams. As spilled petroleum products become weathered, the aromatic fraction of oil is dominated by PAH as the lighter aromatic components evaporate into the atmosphere or are degraded. Because of its low solubility in water, PAH concentrations probably contribute little to acute toxicity; however, lipophilic PAH (those likely to be bonded to fat compounds) may cause physiological injury if they accumulate in tissues after exposure. Even concentrations of oil that are diluted sufficiently to not cause acute impacts in marine organisms may alter certain behavior or physiological patterns. Sublethal effects that may occur with exposure to PAH include impairment of feeding mechanisms for benthic fish and shellfish, growth and development rates, energetics, reproductive output, juvenile recruitment rates, increased susceptibility to disease and other histopathic disorders, and physical abnormalities in fish larvae. Effects of exposure to PAH in benthic species of fish include liver lesions, inhibited gonadal growth, inhibited spawning, reduced egg viability and reduced growth. Toxicity responses to winter flounder (*Pseudopleuronectes americanus*) exposed to PAH and other petroleum-derived contaminants, include: liver and spleen diseases, immunosuppression responses, tissue necrosis, altered blood chemistry, gill tissue clubbing, mucus hypersecretion, altered sex hormone levels, and altered reproductive impairments. For Atlantic cod (*Gadus morhua*) exposed to various petroleum products, responses included reduced growth rates, gill hyperplasia, increased skin pigmentation, hypertrophy of gall bladder, liver disease, delayed spermatogenesis, retarded gonadal development and other reproductive impairments, skin lesions, and higher parasitic infections. Effects from exposure of aquatic organisms to PAH include: carcinogenesis, phototoxicity, immunotoxicity, and disturbance of hormone regulation. Fuel, oil, and some hydraulic fluids contain PAH which can cause acute and chronic toxicity in marine organisms, and toxic effects of exposure to PAH have been identified in adult finfish at concentrations of 5-50 ppm and the larvae of aquatic species at concentrations of 0.1-1.0 ppm (Logan 2007). Observed effects of fish exposed to PAH include decrease in growth, cardiac disfunction, lesions and tumors of the skin and liver, cataracts, damage to immune systems, estrogenic effects, bioaccumulation, bioconcentration, trophic transfer, and biochemical changes. PAHs can be toxic to meroplankton, ichthyoplankton, and other pelagic life stages exposed to them in the water column. Short-term impacts include interference with the reproduction, development, growth, and behavior (e.g., spawning, feeding) of fishes, especially early life-history stages. Although oil is toxic to all marine organisms at high concentrations, certain species are more sensitive than others. In general, the early life stages (eggs and larvae) are most sensitive, juveniles are less sensitive, and adults least so.

There are no rockfish-specific PCB threshold data available to determine whether observed concentrations are likely to adversely affect rockfish health (West et al. 2001).

SENSITIVITY SCORES

Mortality: 3 (juvenile forms of all species); 2 (adult forms of all species); Sensitivity scores reflect that most fish species are particularly sensitive to contaminants/pollution during their early life history.

Behavior: 2 (juvenile and adult forms of all species). Response behavior to organic pollution does not change (i.e., no avoidance) sensitivity.

Physiology: 3 (adult forms of all species); 2 (juvenile forms of all species). Body size, age, feeding ecology, and trophic position are some of the most important factors determining bioaccumulation in marine fishes. Most species have no apparent physiological response (i.e. they do not metabolize these pollutants to remove them) that would reduce sensitivity to this threat.

COASTAL SEAWATER EXCHANGE

Threat data layer description, from Halpern et al. (2009) : We mapped the location of all coastal power plants that lie on the coastline from the Platts database (http://www.platts.com/Analytic%20Solutions/Custom/gis/index.xml), and applied a 3km buffer around these power plants as an estimate of the scale of their impact. We found 5 plants in Puget Sound, 1 in Oregon, and 17 in central and Southern California.

Effects: Coastal power plants (and deslination plants) draw in huge amounts of marine water for cooling purposes, creating an area around the intake pipes where larvae and small plants are entrained. These entrainment 'plumes' will vary in size and shape depending on ocean currents and the size of the power plant. The construction and operation of water intake and discharge facilities can have a wide range of physical effects on the aquatic environment including changes in the substrate and sediments, water quality and quantity, habitat quality, and hydrology. Most facilities that use water depend upon freshwater or water with very low salinity for their needs (Johnson et al. 2008).

The entrainment and impingement of fish and invertebrates in power plant and other water intake structures have immediate as well as future impacts to estuarine and marine ecosystems (Johnson et al. 2008). Not only is fish and invertebrate biomass removed from the aquatic system, but the biomass that would have been produced in the future would not become available to the ecosystem. Water intake structures, such as power plants and industrial facilities, are a source of mortality for managed-fishery species and play a role as one of the factors driving changes in species abundance over time. Organisms that are too large to pass through in-plant screening devices become stuck or impinged against the screening device or remain in the forebay sections of the system until they are removed by other means.

SENSITIVITY SCORES

Mortality: 3 (juvenile forms of all species); 1 (adult forms of all species); Mortality effects would be most significant for larval or juvenile life history stages entrained in cooling system intakes.

Behavior: 3 (juvenile forms of bocaccio and canary); 2 (juvenile forms of hake and sablefish, adult forms of all species). Behavioral effects would primarily be observed in nocturnally active species that are attracted to structure or discharge plumes that increase local ocean temperatures.

Physiology: 2 (juvenile and adult forms of all species. Behavioral effects would primarily be reflected in discharge plumes that affect local ocean temperatures.

SEDIMENT DECREASE

Threat data layer description, from Halpern et al. (2009): See Sediment increase, above.

Effects: Changes in sediment regimes can affect marine ecosystems due to decreases in sediment input (largely resulting from river damming). Dams affect the physical integrity of watersheds by fragmenting the lengths of rivers, changing their hydrologic characteristics, and altering their sediment regimes by trapping most of the sediment entering the reservoirs and disrupting the sediment budget of the downstream landscape (Heinz Center 2002) (Johnson et al. 2008). Because water released from dams is relatively free of sediment, downstream reaches of rivers may be altered by increased particle size, erosion, channel shrinkage, and deactivation of floodplains (Heinz Center 2000). The consequence of reduced sediment also extends to long stretches of coastline where the erosive effect of waves is no longer sustained by sediment inputs from rivers (World Commission on Dams, 2000).

The effects to fishes of a reduced sediment regime would be indirect and primarily experienced through the long-term loss of soft-bottom habitat features and coastal landforms and/or changes to benthic habitat composition.

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species). Sediment decreases are unlikely to result in any mortality to these marine species; if there is any response, it would likely be behavioral in nature.

Behavior: 2 (juvenile and adult forms of hake, juvenile form of sablefish); 1 (adult forms of all species except hake). There are few behavioral responses that would increase sensitivity to sediment decreases, although water column species that rely on low water clarity for predation refuge may avoid these areas. This "threat" may actually open up new habitat to hard substrate site-attached species and they may move to these new habitats.

Physiology: 2 (juvenile and adult forms of all species). There is no apparent physiological response that would reduce or increase sensitivity to this threat.

SEDIMENT INCREASE

Threat data layer description, from Halpern et al. (2009) : We modeled changes in sediment regimes for all watersheds feeding in to the California Current using a 5-step process. First, we created a new, very high resolution watershed layer (see above). Second, we used the sediment release model developed by Syvitsky and colleagues (Syvitski et al. 2003) to model natural levels of sediment runoff from these watersheds without dams in place. This model is based on 4 parameters: maximum relief, latitude, basin area, and temperature, which serves as a proxy for rainfall. Third, to calculate changes in sediment input we placed onto the landscape all moderate-sized or larger dams included in the National Inventory of Dams produced by the Army Corps of Engineers for the year 2005 (http://www.nationalatlas.gov/index.html). We focused on dams >50ft high and/or with a capacity >5000 acre-feet (N=809). Fourth, we reran the sediment model on the sub-watersheds to determine how much sediment reached each dam from its own sub-watershed (i.e., excluding upstream sub-watersheds), using average current temperature data from the years 1996-2006 (http://www.prism.oregonstate.edu) and the other parameters listed above. Finally, we applied each dam's sediment trapping efficiency rate to its sub-watershed, releasing the appropriate amount of sediment below that dam into the downstream sub-watershed, and continued this process until the sediment reached the coastal pourpoint. This analysis therefore also accounted for changes in sediment runoff from these watersheds due to changing climate (i.e. increases in precipitation correlated with rising temperature). For those watersheds without dams, this process produced a new 'natural' value of sediment input that in almost all cases was higher than the pre-industrial estimates due to climate change increasing local temperatures. Consequently, this process produced two stressor layers, increases in sediment (exclusively those watersheds without dams) and decreases in sediment (mostly watersheds with dams). Where temperature changes increased sediment but dams decreased it, the increase (always the smaller of the two) was subtracted from the decrease to produce a single value for the sub-watersheds and the final watershed pourpoint.

Effects: Changes in sediment regimes can affect marine ecosystems due to increases in sediment input (due to land use practices and climate change that can increase precipitation and runoff). Much of the available data come from bioassays that measure acute responses and required high concentrations of suspended sediments to induce the measured response, usually mortality (Wilber and Clarke 2001). Although anadromous salmonids have received much attention, little is known of behavioral responses of many estuarine fishes to suspended sediment plumes. There is a high degree of species variability in response to sedimentation; reports of ''no effect'' were made at concentrations as great as 14,000 mg/L for durations of 3 d and more (oyster toadfish and spot) and mortality was observed at a concentration/duration combination of 580 mg/L for 1 d (Atlantic silversides). For both salmonid and estuarine fishes, the egg and larval stages are more sensitive to suspended sediment impacts than are the older life history stages.

SENSITIVITY SCORES

Mortality: 2 (juvenile and adult forms of all species). Increases in suspended sediments could affect predator-prey interactions, whereas increased sediment loads would affect substrate composition; without accounting for loss/burial of predation refuge.

Behavior: 2 (juvenile and adult forms of hake, juvenile form of sablefish); 1 (juvenile and adult forms of bocaccio and canary rockfish; adult form of sablefish). We assume that the long-term effects of sediment increases would be to change the composition of nearshore marine habitats from coarse and rocky substrates to soft sand-mud, thereby inducing behavioral responses (attraction/avoidance) that would reduce sensitivity to this threat by marine species with specific benthic habitat preferences (i.e. rockfishes, Petrale sole, adult sablefish).

Physiology: 2 (juvenile and adult forms of all species). None of these species have apparent physiological responses that would reduce or increase sensitivity to this threat.

SHIPPING ACTIVITY

Threat data layer description, from Halpern et al. (2009) : Data was combined from the global mapping effort (Halpern et al. 2008), clipped to the California Current region, with data on ferry traffic within the region. Ferry routes were digitized, and the ferry schedule data were converted into annual ship traffic data by multiplying the number of daily ferry trips by 260 for weekdays (5 days x 52 weeks) and 104 for weekends, summed for total annual trips, and then applied to the appropriate ferry route.

Effects: Commercial shipping activity can lead to ship strikes of large animals, noise pollution, and a risk of ship groundings or sinkings. Data on effects of commercial shipping on fish suggests most responses are behavioral in nature, and mortality is not a major concern. Recent studies suggest fish are actually attracted vessels, rather than being repelled by them; fish even appeared to be attracted to noisy commercial vessels, and recorded swimming velocities of fish schools suggest that fish do not become scared by noisy, passing ships (Rostad et al. 2006). Vessel activity in coastal waters is generally proportional to the degree of urbanization and port and harbor development within a particular area (Johnson et al. 2008). Benthic, shoreline, and pelagic habitats may be disturbed or altered by vessel use, resulting in a cascade of cumulative impacts in heavy traffic areas. The severity of boating-induced impacts on coastal habitats may depend on the geomorphology of the impacted area (e.g., water depth, width of channel or tidal creek), the current velocity, the sediment composition, the vegetation type and extent of vegetative cover, as well as the type, intensity, and timing of boat traffic. Recreational boating activity mainly occurs during the warmer months which coincide with increased biological activity in east coast estuaries. Similarly, frequently traveled routes such as those traveled by ferries and other transportation vessels can impact fish spawning, migration, and recruitment behaviors through noise and direct disturbance of the water column. Other common impacts of vessel activities include vessel wake generation, anchor chain and propeller scour, vessel groundings, the introduction of invasive or nonnative species, and the discharge of contaminants and debris.

SENSITIVITY SCORES

Mortality: 1 (juvenile and adult forms of all species). Shipping strikes, groundings, and noise pollution not likely to affect these species in the water column or near the bottom.

Behavior: 2 (juvenile and adult forms of all species). None of these species have behavioral responses that would reduce or increase sensitivity to shipping strikes, groundings, and noise pollution.

Physiology: 2 (juvenile and adult forms of all species). None of these species have apparent physiological responses that would reduce or increase sensitivity to shipping strikes, groundings, and noise pollution.

SPECIES INVASION

Threat data layer description, from Halpern et al. (2009) : The potential impact of invasive species was modeled in the same manner as in the global project (Halpern et al. 2008). Briefly, for each port, the annual tonnage of goods passed through the port (i.e., port volume) was used as a proxy measure for ship traffic and therefore probability of invasive species introduction. Past research has shown this to be a reasonable approach to estimating numbers of invasive species at a location (Carlton and Geller 1993; Drake and Lodge 2004). Port volume data were obtained from the global database (Halpern et al. 2008). These port volume values were then plumed away from each port using a diffusive model and a maximum distance of spread set at 27km for the largest port in the region, Long Beach, California.

Effects: Introductions of nonnative invasive species into marine and estuarine waters are considered a significant threat to the structure and function of natural communities and to living marine resources in the

United States (Carlton 2001; Johnson et al. 2008). The mechanisms behind biological invasions are numerous, but generally include the rapid transport of invaders across natural barriers (e.g. plankton entrained in ship ballast water, organisms contained in packing material (Japanese eelgrass *Zostera japonica*) or fouling on aquaculture shipments, aquarium trade with subsequent release to natural environments). Nonnative species can be released intentionally (i.e., fish stocking and pest control programs) or unintentionally during industrial shipping activities (e.g., ballast water releases), aquaculture operations, recreational boating, biotechnology, or from aquarium discharge.

SENSITIVITY SCORES

Mortality: 3 (juvenile forms of all species). 2 (adult forms of all species). Effects of non-native predators, competitors, prey, and/or habitat structural elements likely lethal for juveniles, sub-lethal for adults.

Behavior: 3 (juvenile and adult forms of all species). Native species are not adapted to behaviorally resist the effect of non-native predators, competitors, prey, and/or habitat-forming species. Behavioral interactions would therefore, likely increase the sensitivity of these marine species to population-wide effects.

Physiology: 2 (juvenile and adult forms of all species). None of these species have physiological responses that would reduce or increase sensitivity to invasive species.

COASTAL TRASH

Threat data layer description, from Halpern et al. (2009) : Good spatial data do not exist for marine debris at sea, but beach clean up efforts provide data for the amount of trash that ends up on (and impacts) intertidal ecosystems. The State of California collects county-level statistics on the amount of trash collected from coastal areas each year as part of the California Coastal Commission Public Education Program (http://www.coastal.ca.gov/publiced/pendx.html). We extracted data for the years 2003-2007 and calculated the average amount of trash collected, and then divided this county-level average by the number of coastal pixels per county to obtain the average pounds of trash collected per 1 km^2 of coastline. Similar data do not exist for Washington, Oregon, or Baja, but we chose to include this layer given its importance and length of the California coastline relative to the region. Intertidal ecosystems in California will have marginally higher cumulative impact scores due to this inclusion.

Effects: Marine debris causes stress to organisms that ingest it mistaking it for food, most notably sea birds, sea turtles, and some sea mammals. Ingestion by some species, resulting in mortality (Derraik 2002). Behavioral effects – may concentrate fish (FAD, Artificial reefs).

SENSITIVITY SCORES

Mortality: 2 (juvenile and adult forms of all species). Coastal trash effects were considered primarily solid trash from land-based sources. The most likely mortality effects of solid trash would be from ingestion (including minute plastic particles) or entanglement, but there are only a few good examples of this in the marine literature.

Behavior: 3 (juvenile and adult forms of bocaccio and canary rockfish); 2 (juvenile and adult forms of hake, juvenile form of sablefish); 1 (adult form of sablefish). Most likely behavioral effects of solid trash would be attraction to sunken or floating debris by structure-associated species, such as rockfish, and avoidance by structure-averse species. Other species/forms would not change their behavior.

Physiology: 2 (juvenile and adult forms of all species). There is no physiological response that would enhance or reduce these species' sensitivity to coastal trash.

CLIMATE CHANGE THREATS

We did not include time series data for these climate change threats, because they are dealt with in more precise detail elsewhere in the IEA process. They were included to provide perspective to the magnitude of other non-fisheries related threats. However, the details of the data for each threat layer are included below as well as the scoring rationale for the Sensitivity scores for each threat.

OCEAN ACIDIFICATION

Data layer description: Data for all three measures of climate change stressors (sea surface temperature anomalies, UV radiance anomalies, and ocean acidification) were taken from global data described elsewhere (Halpern et al. 2008), clipped to the California Current region. Briefly, SST anomalies measure the number of times SST was higher in the most recent five years (2000-2005) relative to the longer term (1985-2005) variance (measured as standard deviation). UV radiation anomalies were calculated in the same manner, but with a shorter range of data comparison (2000-2004 vs. the long term variance 1996-2004). Ocean acidification was modeled as the change in aragonite saturation state from pre-industrial times (1870) to modern times (2000-2009). All data layers were represented at $1km^2$ resolution.

Effects: Increased acidity in oceans is expected to effect calcium carbonate availability in seawater, which would lower the calcification rates in marine organisms (e.g., mollusks and crustaceans, some plankton, hard corals) (IPCC 2007). Alteration of water alkalinity could have severe impacts on primary and secondary production, which have implications at the ecosystem level (Fabry et al. 2008). Increasing atmospheric carbon dioxide concentrations and altered seawater carbonate chemistry could have a range of effects, including physiological changes to marine plankton on the organismal level, changes in ecosystem structure and regulation, and large scale shifts in biogeochemical cycling (Fabry et al. 2008). For example, increased carbon dioxide concentrations are predicted to decrease the carbonate saturation state and cause a reduction in biogenic calcification of corals and some plankton, including coccolithophorids and foraminifera; however, increasing carbon dioxide concentrations could increase the rates of photosynthetic carbon fixation of some calcifying phytoplankton.

Juvenile salmon in weakly acidic freshwater streams do not respond to alarm cues (Leduc et al. 2006). The hatchling stages of some fish species appear fairly sensitive to pH decreases on the order of 0.5 or greater, but high CO_2 tolerance developed within a few days of hatching (Fabry et al. 2008).

SENSITIVITY SCORES

Mortality: 3 (juvenile forms of all species); 2 (adult forms of all species); Theoretically lethal (3) for all life history stages based on effects of ocean acidification on primary and secondary production being manifested at ecosystem level, but scored sublethal (2) for adults based on no specific literature documenting mortality in these species.

Behavior: 3 (juvenile and adult forms of all species). The current body of literature is beginning to suggest that many marine and freshwater fish species display behavioral responses (e.g., attraction to predator smells) that may increase sensitivity to ocean acidification.

Physiology: 2 (juvenile and adult forms of all species). None of these species are known to have physiological responses that would reduce or increase sensitivity to ocean acidification.

SEA SURFACE TEMPERATURE

Data layer description: Data for all three measures of climate change stressors (sea surface temperature anomalies, UV radiance anomalies, and ocean acidification) were taken from global data described elsewhere (Halpern et al. 2008), clipped to the California Current region. Briefly, SST anomalies measure the number of times SST was higher in the most recent five years (2000-2005) relative to the longer term (1985-2005) variance (measured as standard deviation). UV radiation anomalies were calculated in the same manner, but with a shorter range of data comparison (2000-2004 vs. the long term variance 1996-2004). Ocean acidification was modeled as the change in aragonite saturation state from pre-industrial times (1870) to modern times (2000-2009). All data layers were represented at 1km^2 resolution.

Effects: Temperature affects nearly every aspect of marine environments, from cellular processes to ecosystem function (Johnson et al. 2008). The distribution, abundance, metabolism, survival, growth, reproduction, productivity, and diversity of marine organisms will all be affected by temperature changes. Most marine organisms are able tolerate a specific temperature range and will become physiologically stressed or die after exposure to temperatures above or below the normal range. At sublethal levels, temperature extremes can effect the growth and metabolism of organisms, as well as behavior and distribution patterns. Reproduction timing and the rates of egg and larval development are dependent upon water temperatures. The reproductive success of some cold water fish species may be reduced if water temperatures rise above the optimum for larval growth (Johnson et al. 2008). Stratification could affect primary and secondary productivity by altering the composition of phytoplankton and zooplankton, thus affecting the growth and survival of fish larvae. However, in warmer ocean areas phytoplankton became less abundant as sea surface temperatures increased further, possibly because warm water blocks nutrient-rich deep water from rising to the upper strata where phytoplankton exist; effects have been implicated as a factor in the decline in North Sea cod stocks. Impacts to the base of the food chain would not only affect fisheries but will impact entire ecosystems. Mountain (2002) predicted a northward shift in the distributional patterns of many species of fish because of increasing water temperatures in the Mid-Atlantic region as a result of climate change.

SENSITIVITY SCORES

Mortality: 2 (juvenile and adult forms of all species). Temperature is lethal (3) for all species at excessive levels and can have cascade of ecosystem effects due to changes in primary and secondary production. However, mortality risk was scored sublethal (2) based on primary responses (e.g., reduced growth, reproduction, etc.) observed in literature reviews for these species.

Behavior: 3 (juvenile and adult forms of bocaccio and canary rockfish); 1 (juvenile and adult forms of hake and sablefish). Most species display some form of behavioral thermoregulation (e.g., range shifts, vertical movement) that reduces their sensitivity to sea surface temperature change; however, some rockfish species have strong habitat preferences that may increase their sensitivity to this threat.

Physiology: 3 (juvenile and adult forms of bocaccio and canary rockfish); 2 (juvenile and adult forms of hake and sablefish). Some species, like rockfish and spiny dogfish, display physiological responses (e.g., energy budgets, growth rates) that increase their sensitivity to sea surface temperature change.

ULTRAVIOLET LIGHT

Data layer description: Data for all three measures of climate change stressors (sea surface temperature anomalies, UV radiance anomalies, and ocean acidification) were taken from global data described elsewhere (Halpern et al. 2008), clipped to the California Current region. Briefly, SST anomalies measure the number of times SST was higher in the most recent five years (2000-2005) relative to the longer term (1985-2005) variance (measured as standard deviation). UV radiation anomalies were calculated in the same manner, but with a shorter range of data comparison (2000-2004 vs. the long term variance 1996-2004). Ocean acidification was modeled as the change in aragonite saturation state from pre-industrial times (1870) to modern times (2000-2009). All data layers were represented at 1km^2 resolution.

Effects: The eggs and larvae of many fish are sensitive to UV-B exposure. However, imprecisely defined habitat characteristics and the unknown effect of small increases in UV-B exposure on the naturally high mortality rates of fish larvae are major barriers to a more accurate assessment of effects of ozone depletion on marine fish populations (Hader et al. 2003). Visual predators, including most fish, are necessarily exposed to damaging levels of solar UV radiation. Skin and ocular components can be damaged by UV, but large differences are found between different species. Coral reef fishes can adapt to the UV stress by incorporating UV-absorbing substances, which they acquire through their diet, into their eyes and epidermal slime.

In addition to direct effects, including damage to biological molecules such as DNA and proteins and the generation of reactive oxygen species, photoactivation of organic pollutants and photosensitization may be detrimental (Hader et al. 2003). The damaging effects on eggs and larval stages may be enhanced by polycyclic aromatic hydrocarbons (PAHs) such as retene, which is a pollutant from pulp and paper mills. Solar UV radiation has been shown to induce DNA damage in the eggs and larvae of the Atlantic cod, where larvae were more sensitive than eggs. Artificial UV causes massive apoptosis in larval embryos of Japanese flounders. Use of video taping and measurement of oxygen consumption showed sublethal effects of UV radiation in juvenile rainbow trout. Under worst-case scenarios (60% ozone loss, sunny weather and low water turbulence), solar UV-B eliminated buoyancy and caused mortality within 1 or 2 days. Fish spawning depth strongly correlates with UV exposure. It is not known whether the fish are able to detect and avoid the high UV at shallower depths in the highUV lake or whether this spawning pattern is due simply to differential survival. A similar phenomenon has been observed in bluegill larvae (*Lepomis macrochirus*) in a UV-transparent lake where in 19% of nests the estimated UV-induced mortality of larvae exceeds 25%.Most nests are exposed to relatively low UV levels because they are either located at deeper depths or under overhanging branches (Hader et al. 2003).

SENSITIVITY SCORES

Mortality: 2 (juvenile forms of all species); 1 (adult forms of all species). Evidence of mortality in larvae and eggs, especially when exposed to PAH or other photo-activated chemicals; less obvious, sublethal effects in juveniles; negligible effect on adults.

Behavior: 2 (juvenile forms of bocaccio, canary rockfish, and hake, adult form of hake); 1 (adult forms of bocaccio, and canary rockfish, and sablefish). Deepwater, benthos-associated species/stages and species with negative phototactic response behavior would have reduced sensitivity to this threat (1); all other species/stages would show no apparent behavioral response that would reduce or increase sensitivity to this threat (2).

Physiology: 1 (juvenile and adult forms of all species). Most fish species have physiological responses (i.e., defense mechanisms that prevent or repair UVR damage) that would reduce sensitivity to UV radiation (1).

OTHER POTENTIAL THREATS (NOT USED IN THE CURRENT ANALYSIS – WAITING ON SPATIALLY-EXPLICIT DATA)*

HYPOXIA*

Data layer description: Oxygen data from 2009-2010 Pacific groundfish survey (Keller et al. in prep)

Effects: Demersal fish and benthic invertebrate communities in shallow shelf waters of the California Current were acutely affected by seasonally persistent anoxia and severe hypoxia. In August 2006, surveys along previously monitored (2000 to 2004) transect lines revealed the complete absence of all fish from rocky reefs that normally serve as habitats for diverse rockfish (*Sebastes* species) communities that are of current fishery management concern (Chan et al. 2008). Change in activity such as swimming speed and growth and avoidance of low oxygen conditions by changing the habitat have been observed in the marine environment quite frequently (Ekau et al. 2010). Sablefish, as well as a number of other fish species (e.g., Dover sole) exploit oxygen minimum zones; oxygen interfaces may be important to these species as aggregation sites or predation refugia (Levin 2003).

SENSITIVITY SCORES

Mortality: 2 (juvenile forms of all species, adult forms of all species except sablefish); 1 (adult form of sablefish). Most species, with the exception of adult sablefish, exhibit sublethal effects to hypoxia.

Behavior: 1 (juvenile forms of all species, adult forms of all species except sablefish); 1 (adult form of sablefish). Most species display some form of avoidance/movement behavior that would reduce their sensitivity to hypoxic zones (1); however, some species like rockfish may have strong habitat preference behavior that limit their mobility and may increase their sensitivity this threat (?).

Physiology: 2 (juvenile forms of all species, adult forms of all species except sablefish); 1 (adult form of sablefish). Sablefish have a physiological response that decreases their sensitivity to hypoxic zones (1); all other species do not show a response that would enhance or reduce their sensitivity (2).

HARMFUL ALGAL BLOOMS*

Data layer description: none

Effects: Mortality via direct or indirect exposure; species effect varies based on location in water column, species, mechanism, etc. (Landsberg 2002). There are few specific examples in literature that address effects on these four species, however.

SENSITIVITY SCORES

Mortality: 2 (juvenile and adult forms of all species). Theoretically lethal (3), but scored sublethal (2) based on no specific literature documenting mortality in these species.

Behavior: 2 (juvenile and adult forms of hake and sablefish); 1 (juvenile and adult forms of bocaccio and canary rockfish). Most species show no behavioral response that either reduces or increases their sensitivity to HABs. However, demersal species (e.g., rockfish, sole) have reduced sensitivity to this threat (1) due to their association with bottom habitats.

Physiology: 2 (juvenile and adult forms of all species). These species do not show a physiological response that would enhance or reduce their sensitivity to HABs (2).

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